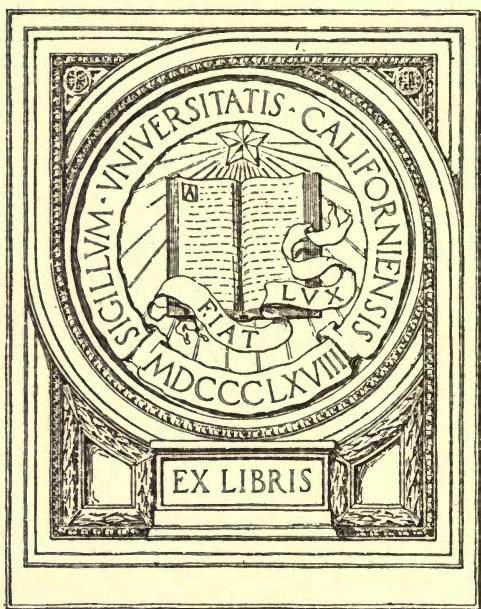


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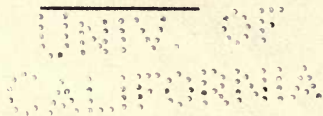
MINERALOGY

A Short Course in Mining Science, Designed for the Student,
Miner, Prospector and General Mining Man. Written
From the Standpoint of a Practical Field Man.

REVISED EDITION

BY

W. D. HAMMAN, B. Sc.



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PREFACE TO SECOND EDITION

The intrusion of "Practical Geology and Mineralogy" into the domain of Mining Science was attended with serious misgivings on the part of the author. A fair warning had been given by those competent to advise that technical subjects could only be successfully treated in technical language; that any departure from recognized standards would prove futile if not an absolute failure.

With the prospector's instinct for new fields and with a firm belief that a common school education qualifies any one to understand basic principles of any science, when presented in common everyday language, the well meant friendly advice had to go into the discard.

The occasion for a second edition should be conclusive evidence that the author's estimate of the ability of the average person was not wholly incorrect, as no work lacking in substantial merit can well have a renewed lease of life.

The kindly criticism of this work by scientists who have found it worthy of review, is appreciated and has enabled a correction of some errors of principle and expression in the first edition. However a greater source of satisfaction has been afforded by kind words of approval from students in the "School of Experience"; That the practical

miner and prospector in the field have been able to understand and profit by the elementary lessons in mining science, is nothing short of an inspiration.

The various subjects treated in this work would make several volumes if given full consideration. The author's aim has been simply to open up each subject—state fundamental principles and facts in an interesting way, hoping to stimulate a desire on the part of the reader for more knowledge.

Students and perhaps graduates of mining schools often forget elementary principles, so that a brief review such as is herein given often proves of much value in removing mental cobwebs.

As a text book for study at home as well as in schools giving a brief course in mining, many have found this little book of great service, and the hope is cherished that this field of usefulness will be greatly enlarged.

Conscious that all human effort is imperfect, the author will welcome constructive criticism from any source.

W. D. H.

August, 1915.

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AUTHOR'S PREFACE

There are perhaps more people interested in mining who know nothing of the underlying principles than in any other industry. This is largely due to the widespread belief that it is all a matter of chance or luck, whether success or failure results. Years of practical experience in the different branches of the mining business have convinced the author that nearly all failures in mining are due to ignorance of the elementary principles of mining science. This is no reflection on those engaged in mining as no other industry contains a larger proportion of intelligent, wide-awake people, but this condition is due almost wholly to the absence of practical, non-technical books on mining subjects. Realizing this serious handicap to the mining business, the author has endeavored to rise to the occasion, and supply this "long-felt want."

Science is a dry subject to many, especially if presented in academic style and technical language. While it is impossible to treat science in story-book fashion, yet the author believes it is possible to popularize mining science, by "cutting out" unimportant matter and confining the scope to simple, practical every-day phases of the mining business.

There is a fascination about mining, and the author's central idea has been to present his several subjects in such a way as to arouse interest and encourage the further study of mining science. Illustrations have been freely used to break

the monotony and to firmly fix the principles in the mind of the reader, by means of these object lessons.

Nearly every subject is introduced by a pertinent question and the paragraph following is devoted to answering the query raised, so that a live practical issue is raised on every page.

Centuries ago the wisest man that ever lived said, "There is nothing new under the sun." The same old sun shines today and beholds nothing new; elements and principles will ever remain the same throughout all time.

Mining is an old industry and much has been said and written concerning it. But mining wisdom, like the precious element—gold—though everywhere present, yet requires to be collected, concentrated and refined to be of use to man. This has been the task at hand in the preparation of this work and it is for the reader to judge the merits of the processes used.

The author has discovered no new facts or principles, but has not hesitated to appropriate anything of practical value within range and no acknowledgment can well be made as to any particular source.

A list of the authorities consulted in the preparation of this work would read too much like a catalogue of the leading books on mining science, and would serve no useful purpose. Whatever merit this volume contains is due to sampling, grading and concentrating the rough material at hand, carefully selecting the rich "Pay-streak" and consigning the "low-grade" to the "waste dump."

Care has been taken, however, to be accurate, and nothing herein contained lacks support of authority. Despite constant

watchfulness, however, errors will creep in so that the author's meaning is sometimes changed.

The technical reader may find cause to criticise the elementary character of this work, but it was not designed for his benefit; although he may find profit in a few lessons learned in the School of Experience.

The author has constantly kept in view the needs of the great mass of mining men, who have not had the advantage of a course in a Mining School. While the limits of such a work will not permit more than brief outline of the subjects treated, yet such important subjects as "Ore Deposits," are discussed so fully that even the mining expert may possibly derive something of benefit therefrom.

Should this work find favor with that noble band of mining men who are seeking to extract pure "untainted" wealth from Nature's Vast Treasure-house, and also assist in raising the standard of the mining industry to that exalted position to which it is justly entitled, the author shall feel amply repaid for his humble efforts.

Faithfully yours,

W. D. HAMMAN.

Los Angeles, California, August, 1911.

PRACTICAL GEOLOGY AND MINERALOGY

Foreword

We are endowed by an *All Wise Providence* with five senses: touch, taste, smell, sight and hearing. The nerves from these organs run to headquarters—the brain, and the sensations are impressed into our consciousness and as a result *We Know*.

For example: We touch a hot iron. A message is flashed along the nerve-wires and recorded in the brain. Instantly an order is dispatched to remove the member. The whole process is complete in the twinkling of an eye. The other four senses act in a similar way, and as a result of this physical evidence a normal mind *Knows*. An idiot, however, with all the senses named, cannot know because he has no mind to receive and use the evidence of the senses. There is also a vast difference in the minds of intelligent persons. One may look at a rock and see nothing of interest, and cast it aside. Another person, trained in Geology and Mineralogy, sees evidence of great riches, material for a lecture discourse or the reflection of God's infinite wisdom and power. What makes the difference? It is partly in the quality of the brain itself, but more largely a matter of

mental training. The man who says he will believe nothing that he cannot see, touch, taste, hear or smell, will hardly reach the first mile-post on the road to knowledge.

Mental and Moral Knowledge

There is another sort of knowledge, equally important, in which the physical senses are seldom called into play. The evidence is often circumstantial, or the result of expert knowledge, or unusual skill in a certain line. And since facts are proven in our courts by such testimony, we also should not hesitate to use it.

For example: The scientific men of his day knew the earth was round, long before Columbus set out on his voyage of discovery. How did they know it? By expert knowledge acquired by long study of the Solar System, such evidence as appealed to their reason, but even in this day, when hundreds of ships yearly sail around it, some still believe the world flat, because it appears so to their narrow vision. Astronomers measure the distance to the sun and calculate the movements of the heavenly bodies so accurately that the exact minute of an eclipse or the crossing of the earth's path by a comet, is predicted long in advance. We also might do this with as much study, but the field of knowledge is too broad and the human mind too limited for any person to learn it all, and for that reason mankind in general is forced to accept a great many things on expert testimony, which we call Authority.

What is Science?

All knowledge, however gained, that has been proven by exact observation and correct reasoning, is called Science. In other words, only truths, facts that have been collected and classified, may properly be called Science. Any collection

of untruths, no matter how cleverly arranged and presented, would be unworthy of the name Science, because unsupported by proper evidence. An actual demonstration is not always necessary, but there must be such probable or moral evidence, on which to base a belief or judgment or the name science may not properly be given it.

What We Do Not Know.

In all sciences there are many mysterious things which we may only know in part and can not fully explain, much less actually prove. In the study of such subjects, a few known things that fit fairly well into each other are often used to construct a theory or hypothesis and with this as a basis of reasoning, we are often able to solve a problem that is otherwise impossible.

To illustrate: Electricity is almost a household necessity today. But we do not even know what electricity is, and no one has yet been able to analyze or define it. Yet we do know how it acts and man has been able to harness it and in a measure control it, but still electricity remains a mysterious force. Science has been unable to fully explain the origin, or fix the actual age of the earth upon which we live, but that does not prevent our laying hold of those truths and facts that science has extracted from the Book of Nature as written in the rocks of the earth.

What Are Natural Laws?

In nature nothing ever "just happens" or comes by "chance." Every where there is order and system. Every creature must have had a Creator. Every design calls for a designer and every law pre-supposes a law-giver.

Law has been well defined to be "a rule of action," so a natural law is nature's rule of action. Nature's laws have

always existed, but man has been slow to discover and classify them. For illustration, as Newton lay under a tree, an apple fell and struck him in the face. This set him to thinking. "Why did not the apple fall up instead of down?" and the result of this thinking led to the discovery of the Law of Gravitation, that all bodies left unsupported fall, in a direct line toward the center of the earth. This, like all other natural laws, is unchangeable; the same for all times and places. In the study of mining science these fundamental principles must ever be borne in mind: "That like causes produce like effects" and "similar effects may always be traced to similar causes"; we must reason from known facts or conditions back to the unknown. These principles underly all science.

To illustrate: If the world was originally a body of gas, as many scientists believe, it condensed just as similar bodies condense today. If it was ever a molten mass, it cooled and became a solid just as a molten globe would now cool and solidify. Likewise, just as elements unite to form compounds in the chemist's laboratory today, so in nature's great laboratory the wonderful variety of mineral compounds have been formed in obedience to the same unchanging natural laws.

PART 1

GEOLOGY



PART I

GEOLOGY

What is Geology?

1. The word Geology is from *geo* (Earth) and *logos* (Study) and literally means Earth study. It is the Science that teaches the Earth's history, as written in the rocks. To be able to read and understand Nature's language, requires a knowledge of Nature's Alphabet, which is to be found in the Science of Geology.

As a Science, Geology is very broad and its proper study requires some knowledge of all the natural Sciences, most particularly Physics and Chemistry, which subjects are outside the scope of this work.

Why a Knowledge of Geology is Necessary

2. The purposes of the study of Geology may be classed under three heads: (a) To enable us to discover the principles and forces that brought the Earth into existence, that governed its development and must control its final destiny; (b) To aid us in tracing the earth's history as recorded in the rocky Book of Nature, in which "every trace becomes a letter, every fragment a word, and every animal or vegetable fossil forms a chapter"; (c) Lastly and above all is the practical benefit to be derived from a knowledge of Geology to the mining man. Within the rock-ribbed earth's crust lies

the mineral wealth he seeks. A knowledge of the earth, its structure, and changes as well as the principles governing the formation of minerals and ore deposits, is absolutely necessary to success in exploring, developing and extracting minerals and metals from Nature's vast store-house.

Nature is not prodigal in distributing her precious gems and metals, whose value so largely depends upon their scarcity. The richest treasures are secreted in the bosom of Mother Earth, and only those who diligently study Nature's laws and labor in harmony with them can secure the reward due to well directed industry.

What is the Earth?

3. The Earth is one in the system of planets that revolve in regular orbits with the sun as the central object. It is third in distance from the sun and sixth in relative size. The Earth is a great magnet, the north pole of which always points to the North Star (Polaris) no matter what position it assumes in its orbit.

The form of the earth is that of a globe or sphere. It is slightly flattened at the poles due to rotation on its axis. Its diameter is about 8,000 miles and its circumference a little over three times that amount. Science tells us there is no such a thing as *rest* in nature; and the earth is a fitting example of this *unrest*. It has a motion on its own axis of more than 1,000 miles an hour and in its orbit around the sun has a speed of eighteen miles a second, or seventy-five times as swift as a cannon ball. In addition to these two motions of the whole Earth, the water and air are in constant motion, while the solid portion of the Earth rises here and falls there, but so slowly as to be scarcely perceptible to the ordinary observer.

What is the Earth's Structure?

4. To simplify the study of the Earth, the Geologist divides it into two parts:

(1) *Crust, and*

(2) *Interior.*

The interior of the earth has not been penetrated to exceed a few miles, beyond which we know nothing, except from the evidence of holes or shafts made in the crust by man.

The Science of Geology relates only to the known portion called the *crust*. Geography divides the Earth's surface into *land* and *water*, but the water which covers three-fourths of the globe is not considered by the Geologist as any part of the earth no more than the atmosphere that surrounds it, so we must consider *air* and *water* apart from earth, simply as *Envelopes* enclosing the Earth, much as an envelope encloses a written letter.

The *highest* mountain rises over five miles above sea level, and the greatest known *depth* of the sea is about eight miles, which would make the lowest point in the sea about thirteen miles nearer the Earth's center than the top of the highest mountain.

In Fig. 1 is shown an elevated section of the Earth's crust, and Fig. 2 is a section of the crust under the sea, which serves to show that there are hills, valleys and mountains under the water similar to those on the land. There is also positive evidence that what is now the Land was covered by the sea, not only once but many times in the Earth's history, but this will be treated in a separate subject.

What Materials Make Up the Earth?

5. Science has analyzed some eighty forms of matter

Fig. 1

ELEVATIONS OF THE EARTH'S CRUST, SHOWN BY SECTIONS.

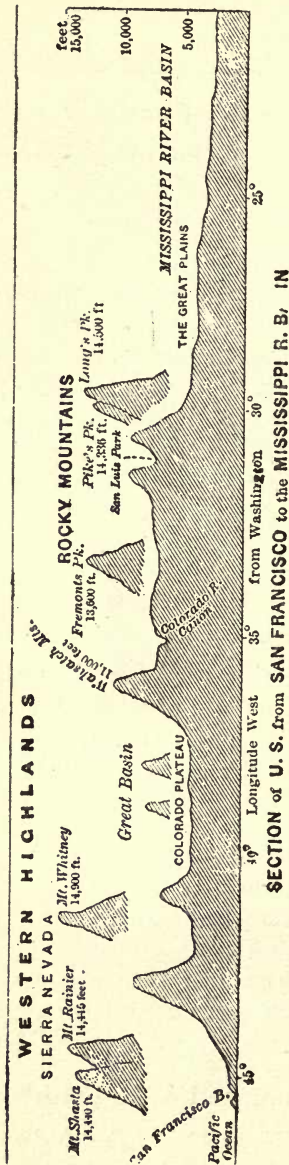
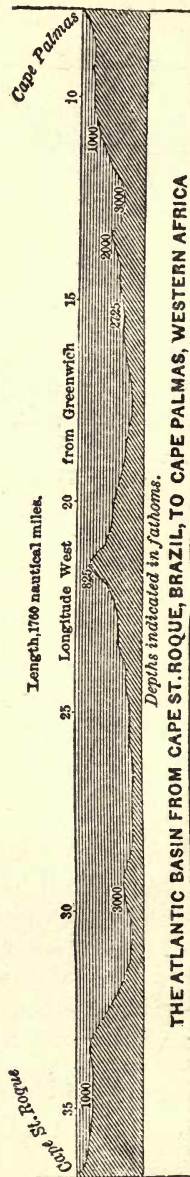


Fig. 2



that make up the Earth's crust, called Elements. These elements are divided into—

- (1) *Solids.*
- (2) *Liquids.*
- (3) *Gases.*

The gaseous portion is mainly found in the atmosphere, which is a mixture of two gases,—Oxygen and Nitrogen, together with small quantities of carbon, acids and alkalies. Water is a *liquid*, but composed of two gases, Oxygen and Hydrogen and small quantities of minerals in solution. *Solids*—These form the Earth's crust though water and gases enter into the composition of most all solids to some extent. Nearly all the metals and minerals are solids, under ordinary conditions.

These three forms of matter may be changed at will in the chemist's laboratory, through the agency of heat. A common example is *ice*—a solid. *Heat* causes this to melt and form water,—a *liquid*; a greater degree of heat changes the *water* into steam,—a gas. By taking away the heat, the steam condenses into water and thence into ice again. There are good grounds for believing that originally all forms of matter were in a gaseous state; in cooling, certain gases united in fixed proportions, forming liquid—*water*, the other gases condensed and separated out forming solids,—*rocks*, and the remaining gases compose the *atmosphere* today.

The forces in nature act and react on the various elements, creating endless changes and combinations that often puzzle the scientist.

What is Known of the Earth's Origin?

6. The Mosaic account of creation is not fully accepted

by Geologists, but any seeming conflict is doubtless due to a misunderstanding of the language of the text. The "Six Days of Creation" in Genesis are now regarded by those who have made translation a study to mean, not six literal *days*, but six *periods* of time of thousands or even millions of years. We shall see later that the *Geologic Ages* correspond very closely to the Bible days, or periods. Science proves the order of creation began with the lowest and advanced to the highest form of animal life until it reached the climax in man, thus confirming the Holy Writ.

"In the beginning, God created the heavens and the earth," declares Moses. Geologists agree that the earth has not always existed, at least not in its present form; although the elements composing it, being indestructible, must always have existed.

We have then two courses open to our reason: first, Accept the Mosaic account as *authority* on the subject; and second, take such known facts, as are shown by proper evidence, and forge these link by link into a chain of reason, and thus endeavor to trace back to the "Great first Cause."

Is the Earth's Interior Hot?

7. The Earth's crust which has been explored by man bears about the same relation to the whole globe as the skin of an apple bears to the whole apple: A slight scratch in the varnish of a school globe would exaggerate by comparison—the deepest shafts dug by man in the real globe.

It is generally believed that the interior of the Earth is in a highly heated condition, perhaps in a molten state. Mere belief is not science, so it is necessary to examine the evidence to support such a belief.

8. (a) THE TEMPERATURE INCREASES WITH DEPTH. The temperature has been taken at different depths in the world's deepest mines. The rate of heat increase varies somewhat in different countries and sections, but always gets warmer from the surface downward; the average being about one degree for each sixty feet of depth. On this basis at a depth of twenty-five miles the principal metals and rocks would melt, and at fifty miles depth the heat would be sufficient to change all elements to the gaseous state, if the pressure of the mass above did not prevent. The temperature at the bottom of a well recently drilled in Pennsylvania, 6775 feet, registered 145 degrees Fahrenheit.

9. (b) WATER FROM ARTESIAN WELLS IS HOT. In some countries Artesian Wells give out water so hot that it is piped through buildings to heat them in the place of fire heat.

10. (c) HOT SPRINGS AND GEYSERS. These are found in many parts of the world varying somewhat in temperature, but all are so hot as to point to a common source within Earth. The Arkansas Hot Springs have a heat of 180 degrees while the Geysers of California and Iceland are fountains of boiling water that will cook an egg in a few minutes.

11. (d) CRUST ELEVATION AND DEPRESSION. The mountains bear unmistakable evidence of having been uplifted by some giant force; in other places what were formerly elevations have sunken to form basins, or to fill the underground cavities formed by uplifts elsewhere. Many of the rocks of the earth's crust have been fused and crystallized, which could have been done by no other agency except heat.

12. (e) VOLCANOES. In many parts of the Earth today there are volcanoes throwing up hot vapors and molten matter, some of which are in the Polar regions of perpetual snow and ice. The craters of extinct volcanoes are found today in many places, some a mile or more in diameter, showing that in former ages volcanoes were more common and of greater violence. They appear to be smoke-stacks of the central fiery furnace beneath. Cities now lie buried by lava and ashes of volcanoes in past ages.

13. (f) EARTHQUAKES. Hundreds of earthquake shocks have been recorded within the last fifty years. The San Francisco earthquake is of such recent occurrence as to be familiar to all.

Scientists are not fully agreed as to the causes, some erroneously attribute earthquakes to tidal waves in the ocean, but these are the effect, not the cause. Geologists generally believe that earthquakes are a result of contraction in the earth's crust due to cooling. All are agreed, however, that these terrific convulsions are due to the *heat* in the interior of the earth.

Conclusion From Evidence

14. This accumulated evidence proves without doubt that the earth's interior *is* very hot. The question then arises, "what is the origin of this heat?" Scientists are not entirely agreed on this question. We know that the sun is the great source of heat as well as light, but the sun can only warm the atmosphere and a little of the outside crust. No fuel within the earth could long burn without the oxygen of the air.

It is well known that *friction* produces heat and primitive man lighted his fires by rubbing together wood or stone

and by striking fire with flint. *Pressure* also generates heat and some scientists conclude the *weight* of the crust and the continual movement of the mass would account for the internal heat, but it hardly seems reasonable to trace the earth's heat to that source alone and this forces us to look to outside causes.

What are Nebulae and Meteors?

15. Look up into the heavens any clear night and behold a bright pathway, called the Milky Way. Astronomers with their delicate instruments distinguish luminous matter about the stars, which by its color in the spectrum they pronounce a gas similar to that manufactured in the laboratory. Comets, those outlaws of the heavens, have also gaseous or nebular tails.

Meteors, or shooting stars, are visible most any clear night. As they fall and sink into the earth their heat fuses the sand and rocks. Scientists estimate one hundred tons of meteors fall on the earth in every twenty-four hours. This raises the questions, *where* do they come from, *why* do they fall to the earth and *what* is the source of their heat? An answer to these questions will no doubt solve the problem as to the source of the earth's interior heat.

What are the Nebular and Meteoritic Theories?

16. The older astronomers constructed a theory known as the Nebular Hypothesis, which supposes the earth's origin was due to nebulae (star-gas) collected in some way, which by revolving cooled and condensed into a shining star; in the process of ages it further cooled and solidified, ceased to shine and became like the moon.

Later scientists conclude the earth began as a solid body, perhaps fragments of suns and stars, collected and fused

into a uniform body by the heat generated in contact. This is called the Meteoritic Theory, and inasmuch as the earth is slowly adding to its size from falling meteors, this latter theory is both plausible and reasonable: hence the earth's interior may not be in a *molten state*, but while very hot, remains *rigid* like steel, owing to the pressure of the outer crust.

These two theories named are not in direct conflict, as solid and gaseous bodies could well combine in accordance with natural laws.

What Practical Use are These Theories?

17. These theories are interesting and cause us to think, a prime necessity in the study of any science. Heat is the great force in causing the changes in the earth itself as well as the materials that compose it, and a knowledge of the *source* of this heat is necessary to understand the formation of minerals and ore deposits, which follow in this book. It has been well said that, "Each theory is a cord on which to string facts that otherwise might be lost"; our theories may yet be thrown away, but our facts—never.

What are the Three Kingdoms?

18. Everything in or upon the earth is classed under three divisions, known as the *Animal, Vegetable and Mineral Kingdoms*.

THE ANIMAL KINGDOM is the highest and last in order of creation. Animals live on organized matter, that is, on other animal and vegetable life. They also make use of mineral matter, but seldom as a food product.

THE VEGETABLE KINGDOM is more closely related to the Mineral Kingdom,—vegetation lives and grows

on minerals, appropriating these from the Earth and from the atmosphere. The Animal and Vegetable are termed *organic* because composed of organs which perform certain functions, while the Mineral Kingdom, having no organs, is called *inorganic*.

THE MINERAL KINGDOM has always existed. It is the basis of all life, both animal and vegetable. When organic matter ceases to live, it changes to mineral. The Animal Kingdom is treated under the Science called Zoology and the Vegetable Kingdom under Botany, but the three Kingdoms are so related that the changes, at least from organic to mineral matter, deserve some mention here.

Myriads of animals have lived and died since creation. The Earth's crust, including the sea bottoms, is one vast cemetery in which lie buried the carcasses of animals that have lived and died in all past ages. Most of the limestone rocks are formed from the animal fossils. Myriads of the lowest orders of sea animals secrete slimes and sediments from the water which are changed to rock. (See Quartz.)

The Vegetable Kingdom also contributes to the formation of minerals. In early ages while the earth and atmosphere were very warm, vegetation grew rank and dense; subsequent changes in the Earth's crust covered up this vegetation and as a result we have mineral coal stored up within the earth for unborn generations. Nature has also secreted within the Earth, mineral oils, from the combined remains of animal and vegetable life.

The Mineral Kingdom then is at once the beginning and end of all forms of matter and as distinguished from organic matter includes everything lifeless, or that which is neither animal nor vegetable.

The Mineral Kingdom includes Solids like rocks and metals, Liquids like water and Gases like oxygen, hydrogen, nitrogen, etc.

The remains of animal and vegetable life—that still retain somewhat their life form of structure, are termed Fossils. This subject is considered under a separate head (See Fossils).

Is the Earth's Crust Stable?

19. We have seen that the Earth's crust is uneven, the elevations being called hills and mountains and the depressions called valleys and basins. These conditions exist under the sea as well as on the land. We have also learned that the Earth's heat generates gases, which, according to natural laws, will seek an outlet along the lines of least resistance. In other words, the weakest point will break first, just as a steam boiler will burst at a defective place. This raises the point—"Why should one part of the Earth's crust be weaker than another?"

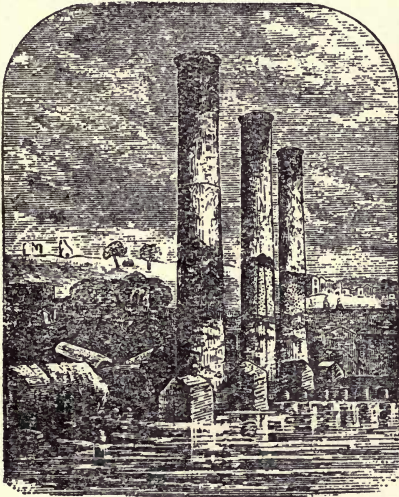
When the Earth was young the crust was thin and broke easily to permit gases and molten matter to escape. As the crust cooled it grew thicker, but pressure of the seas, and accumulated sediments made a denser crust than elsewhere, and not so easily fractured. When we consider that the sea has an average depth of over two miles and in places is eight miles deep, the water pressure is enormous. The pressure on sea bottom at 3000 fathoms (about $3\frac{1}{4}$ miles) depth is three tons to the square inch. From these facts it must be plain that the earth's crust is not stable, and that there is now a constant upward tendency in the land and that the seas are gradually sinking.

What Proofs are There of Earth's Movements Today?

20. Proofs of the raising and sinking of the crust are to be found along the seashore in many countries.

The columns of an ancient Roman Temple are shown in Fig. 3. This temple was built on the seashore. The ground having subsequently sunk, the sea invaded the temple long enough to allow marine shells to burrow into the columns some yards above the pavement. Later the ground

Fig. 3

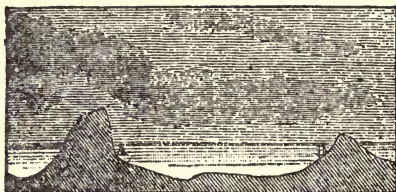


Temple of Serapis, Pozzuoli.

was uplifted again so that today traces of sea shells are seen about midway on the columns. This establishes the fact of both a sinking and an uplift in the land since the temple was built. Landmarks on the coast of Sweden show the land has been raised four feet within a century, while the opposite coast of Norway has sunken. At Sandusky, Ohio,

a tract of land growing hay eighty years ago is now a part of the lake. The land on the east coast of Lake Michigan is rising and the west coast is sinking. These are positive proofs within the memory of man, and when it is considered that a century as we now measure time is but a minute in

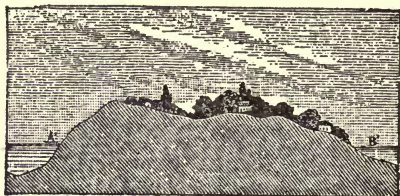
Fig. 4



The sea covering the country from A to B.

the world's history, we may understand the movements which seem slow to us, if extended over millions of years, would account for all the marvelous changes in the earth's crust.

Fig. 5



Then the bottom of the sea rose to A' B'.

In Fig. 4 is shown a section of the earth's crust, the sea covering all the surrounding country from A to B, depositing regularly and slowly its materials held in suspension and its shells; afterwards the bottom of the sea was uplifted as shown in Fig. 5, and the section A¹ to B¹ with all its solid sediments became dry land.

Geologists agree that since the appearance of man on

earth, the continent of North America has been uplifted perhaps by the pressure of the waters on the crust under the Atlantic and Pacific Oceans, which pressure doubtless has also gradually deepened the ocean beds.

What Proofs Exist that Mountains Have Been Uplifted

21. That the mountain systems now shown in Geographies have not always existed is now generally accepted, but it will be well to see if the evidence supports such belief.

(a) Upon many mountain ranges of the world, marine shells have been found, sometimes two miles above sea level. How did they get there? Two ways are possible. First, they have been carried there by living creatures; the shells are far too numerous and the sea usually too distant to make this appear reasonable. A better explanation is that these mountains once lay in the bottom of the sea and were uplifted by a series of violent upheavals, which carried the sea shells along to these great heights.

(b) The structure of high mountain ranges as compared with lower chains and hills furnish further evidence.

Anyone familiar with the character of high mountains, knows that they contain more fractures, fissures and faults than the lower hills. The reason for this is not difficult to see. Hills were either formed by a single heave or eruption, when the earth's crust was soft and easily broken, or were formed by sedimentary deposits and compressed by ponderous masses of overlying earth, and then uplifted.

Hence it is that building stone, free from cracks and of large close-grained blocks, are quarried only in the lower hills, and mountains; the high mountains being formed after the crust became rigid, it required giant forces to fracture the crust, but once an opening was made, a succession of

heaves or eruptions took place, carrying the mass to towering heights; these on cooling were again subjected to the eruptive forces that left them in the broken up condition we find them today, unfit for any structural purpose.

The high mountains are mainly crystalline rocks like granite and contain no fossils, which we shall later see is convincing evidence that they were forced up from great depths in the earth.

What Relation do Mountains Sustain to Mineral Deposits?

22. Look at the map of most any continent and you will see that the mountains parallel the sea coast. The mountain ranges constitute, or rather fill immense faults, in the earth's crust with fire formed rocks. The principal mineral belts of the world, as well as the vein-fissures, usually follow the general course of the mountains. These facts seem to explain the connection of mineral bodies with mountains rather than with valleys and basins; the faulted and fractured condition of eruptive rocks, produce the conditions favorable to the formation of mineral bodies of the precious metals.

What Crust Changes are Due to Action of Air and Water?

23. The atmosphere surrounding the Earth and extending upwards for several miles, is composed of gases and other elements, which cannot be fully explained here. It is sufficient now to say that the action of these elements in the air, on the exposed surface, tends to break up and disintegrate rocks of all kinds by a process called *corosion* or weathering, which literally means eating-away or into, as seen in the common example of iron rusting from exposure to air.

The action of water on the earth's crust is known as *erosion*, which means a wearing away. It is an old saying that "The *constant* dropping of water will wear away the hardest stone," and when we consider the millions of years, the rains have beaten down on the earth's crust, we can understand somewhat of the wearing process due to the action of the water.

What Other Forces Assist Air and Water?

24. Two other forces unite with air and water to produce changes:

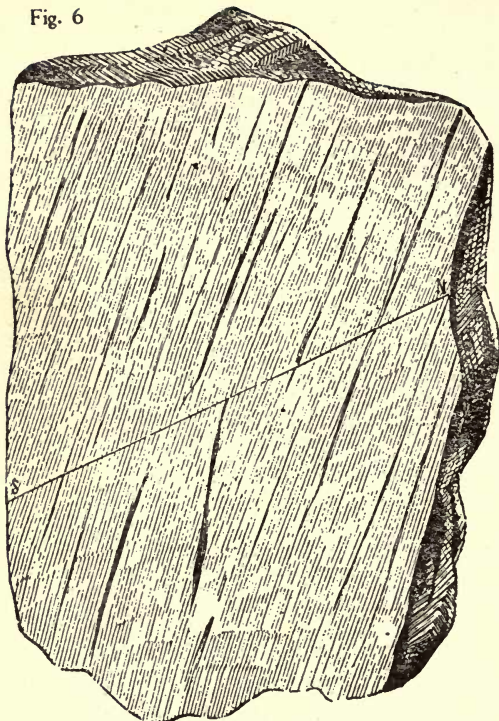
(a) GRAVITY. This is the force that holds the seas in their beds, draws down the rain from the clouds, and keeps the water moving on and on, until it reaches sea level, only to be changed into vapor, rise again, form new clouds and fall again as rain or snow.

(b) THE RADIANT ENERGY OF THE SUN causes the water upon the earth to vaporize, rise and form clouds. The snows that fall on the mountains melt under the sun's rays and start the water tearing downward on its way to the seas. The rocks of the Earth are porous and absorb water; on cold nights and in winter the crust freezes, only to be followed by melting from the sun's heat. This alternate expansion due to heat, and contraction due to cold, is a most powerful factor in breaking up the rocks of hills and mountains.

(c) The Earth contains much mineral coal and oil which is mainly carbon. This once existed combined with the gases of the atmosphere and must have assisted largely in the changes that have been made in the earth's crust.

All these Geologic forces named, acting together wear and

Fig. 6



Boulder Scratches.

Fig. 7



Boulders.

tear away the elevated portion of the crust and spread out the materials in the valleys and basins below, forming sediments that are compressed into dense rocks by accumulated material, which make up three-fourths of the crust as we know it today.

These changes are taking place under our very eyes today, but there is strong reason to believe that in the past ages these forces were more violent and the changes more rapid.

What are Glaciers? . What Changes do They Produce?

25. GLACIERS are masses of snow and ice melted and consolidated. They exist today in high mountains in Europe, in Canada, and in the northwest United States. At the equator the line of permanent snow is 16,000 feet above sea level; towards the poles this line grows lower and lower, until the Arctics are reached, where the "snow-line" is the sea level.

The high mountains in Switzerland furnish the best example of glaciers and their action today. There the snow accumulates in winter to great depths; as summer approaches, under the action of the sun's rays, the snow melts in daytime and freezes into ice at night. The Earth and rocks underneath become loosened from thaws, and by pressure of mass above. This permits the glaciers to move slowly down the mountain sides, producing a scouring, grinding action of the underlying stones, polishing and cutting stria (grooves) in their surfaces like that shown in Fig. 6.

Throughout Europe and in North America, north of the mouth of the Ohio river, rocks are found with polished surfaces and marks (stria) similar to those produced by

Glaciers in Switzerland, which seems to point to the same Glacial origin.

On the west coast of Greenland is a Glacier 1,200 miles long and 2,000 feet high. Some of these vast ice masses become detached in warm weather, float to the southward and are slowly dissolved by the warmer ocean currents. These glaciers often have masses of stone frozen in them. In floating the greater mass is beneath the water, and in coming in contact with rocks or an exposed cliff, grind and mark their surfaces in such a manner as to leave no doubt as to the cause.

What Evidence is There of Glacial Action on the Earth's Crust?

26. We know that the Arctic regions once had a warm climate, as proven by vast coal deposits and bones of tropical animals now found there, and that the land was repeatedly baptized by water. In the course of ages, the conditions changed, the North Temperate Zone was deluged by ice drifting down from the Arctics. This period is known as the *Glacial Age*. (See Quarternary Period.)

The proofs of the *Glacial Age* are the finding of the bones of Polar animals in the Temperate Zone and by the existence of great areas of boulders whose surfaces are polished and scratched just as glacial action results today. Fig. 7 shows a field of boulders thus formed.

The whole of North America east of the Rocky Mountains, and north of the 36th parallel, shows unmistakable evidence of the "*northern drift*." The great Mississippi Valley region has water formed rocks as its natural bed. On top of these are fire-formed rocks, and as there are no

evidences of these having been forced up from below, we must look to other causes. Some places this drift rock is only a slight covering, in other places it is piled up into high hills, and ridges. These fire-formed stones are all more or less rounded and polished, varying in size from cobble stones to boulders weighing many hundred tons.

The parent ledges from which these stones came are always found to the northward, sometimes only a few miles, but often hundreds of miles distant. The streets of Cincinnati are paved with stones believed to have been transported by Glaciers from the region of the Great Lakes. Native copper from Lake Superior Region is scattered over half dozen states to the southward.

These Glacial Boulders have parallel grooves or stria and the sides of hills and mountains of that region show the same polishing and grooving action, on every side except the south. This seems to prove the drift was from the north. These proofs leave no doubt that there *was a Glacial Period* and these changes were due to the action of Glaciers.

What Was the Cause of This Glacial Drift?

27. Geologists fully agree that there was a Glacial Period, but do not altogether agree as to the causes. The weight of authority, however, inclines to the theory that the earth's crust in the Arctic Regions, was uplifted. It is also probable that a corresponding depression was caused in the crust to the southward. In accordance with the laws of gravitation, this sea of ice would seek a lower level and move along the lines of least resistance, which would have been through the great central basin. The Old World suffered a Glacial Period also, which seems to show the Arctic uplift was the main cause of the Glacial Period.

Was the Pacific Coast Affected by Glaciers?

28. The Northern Drift, coming after the Rocky Mountains were elevated, they formed a natural barrier, confining the Glacial ice to the eastward. However, Geologists believe the temperature of the western portion of the continent must have been very cold during this period and that Glaciers were formed throughout the higher Rockies and Sierras, much as are now formed in the Alps. In fact, Glaciers that now exist in Canada, and in the northwest United States, probably had their origin in a former epoch.

Throughout the Rockies and Sierras, fields of boulders may be seen with all the evidence of Glacial marking and polishing.

These Sierra Glaciers in melting, formed torrents of water, which, rushing down the mountain sides, denuded great areas. The process of erosion broke up the auriferous (Gold) rocks, concentrating their gold contents into the rich placers that excited the world in 1849 and still yield up their millions yearly. The Gold Placers of Alaska undoubtedly had their origin in a similar way due to glacial action. (See Fig. 49.)

What are Known as the Geologic Ages?

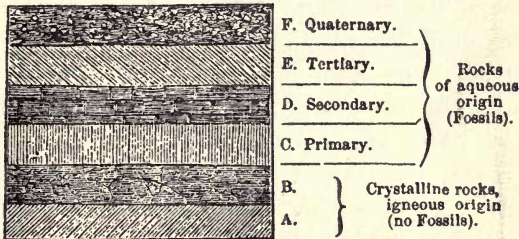
29. The Age of the Earth in years or centuries, is unknown. Some Geologists have attempted to fix the period of time since Creation by taking the record of changes since history began and tracing back to the beginning, but all such estimates run into the millions of years, and being merely guesses, serve no useful purpose.

Although we may not say how old the Earth is, nor even the age of a single strata in the crust, yet we may

correctly say that one strata is older or younger than another, from the evidence showing its earlier or later formation. To illustrate, a crystallized rock, having no sign of animal or vegetable remains, underlying another rock strata, containing fossils, we may safely say the under rock is the older, and the upper rock the younger, without attempting to give the actual age of either.

In Fig. 8 is shown a section of the earth's crust as the rocks would appear in their natural position, the younger above and the older below. The lower strata, A and B, are igneous (fire formed) rocks without fossils, and rock strata

Fig. 8



C, D, E and F are aqueous (water formed) and contain fossils.

If the rocks were always found in the position shown, the Geologist's task would be easy, but as a matter of fact this is seldom the case. For example—granite is one of the primary rocks, that is, if you should dig down through the successive formations, the last rock encountered would likely be granite. Being the foundation rock of the crust, it would necessarily be the oldest.

Our high mountain ranges are largely granite, which often spreads out and overlies all water formed rocks. In

such a case the granite would be the younger, notwithstanding it contained no fossils. The evidence being conclusive that the granite was forced through a crack in the crust after the other rocks were formed, while the unnatural position of the granite would put it in the infant class by comparison.

In the formative periods of the Earth's history, there was a contest between fire and water, the latter finally gaining the mastery. While the conflict was raging, the crust received repeated baptisms of water, the Geologic forces carried the eroded and powdered rocks from the heights to the basins below, forming sedimentary rocks.

These strata, or layers, and their fossil contents, form what are called the *Geological Ages* of the Earth's crust. It is thus that history is indelibly written in the rocks so that man may learn to read it as he would the chapters of a printed book.

How Do Fossils Record Earth's History?

30. The Earth's crust has been undergoing changes from the beginning, and the final chapters in its history are not yet written.

The origin of the Earth, according to the theories (Par. 6), resulted in a globe of fairly even surface. The contraction due to cooling, produced earthquakes and enormous cracks in the crust, through which flowed molten matter to form hills and mountains. The geologic forces disintegrated these elevated portions and the pulverized rock dust was washed down by flooded water, forming into strata in the basins. These were compressed and baked by the Earth's heat into the sedimentary rocks.

These strata were not formed over the entire earth at the

same time for the reason that when one continent was elevated, another was covered with the sea. This accounts for the absence of a strata in some countries. Often a strata found in one country will have a corresponding strata in another country of a very different material, the presence of the same fossils being the only connecting link. To illustrate:—The limestone strata of North America corresponds closely in age with the chalk strata of Western Europe.

Then there are salt water fossils and fresh water fossils; that is, fossils of land animals and sea animals, fossils of sea plants and land plants. This raises the question: How can the fossils be distinguished? This largely belongs to the sciences of Zoology and Botany, but there are certain basic principles that aid us in this matter, which will have brief notice here.

If a rock contains sea animal fossils, it proves that the rock crust was beneath the sea at the period of formation. Similarly the presence of land animal or vegetable fossils proves that portion of the crust was elevated while the rock was being formed.

Thus the fossils furnish the link to unite the parts of the geologic chain that encircles the Earth. The fossils are called the "Medals of Creation," which tell the successive creations of animal and plant life, just as the coins of a buried city unknown to history tell the relative age and place of such a city in the world's history. Each formation has its peculiar fossils and the naturalist is often able to restore the form of a plant or animal and determine its habits by a fragment of a tooth or bone. One naturalist was able to restore a fish and classify it from a single scale fossil.

There are no sharply defined lines separating the geologic ages. They fade into each other as the plain blends into the mountain, yet each as a whole has its peculiar characteristics, so that those trained to this work seldom have any difficulty.

How Is the History of the Earth's Crust Divided?

31. By referring to the Geological Section, page 48, you will see the rock strata arranged in the order they were formed. The age increases from the surface downward, but this perfect horizontal arrangement is rare, as the Earth movements have tilted up the various formations at different angles. Intrusion of igneous matter from below also causes endless twisting, folding and dislocation of rock formations.

Geologists divide the history of the crust into *Eras*, according to the animal and vegetable life that then existed, as follows:

- (1) *Azoic Era* (without life).
- (2) *Paleozoic Era* (Ancient Life).
- (3) *Mesozoic Era* (Middle Life).
- (4) *Cenozoic Era* (Recent Life).

These *Eras* are divided into what are called *ages*, according to their principal fossils, as follows:

- (A) *Silurian Age* (Age of Mollusks).
- (B) *Devonian Age* (Age of Fishes.)
- (C) *Carboniferous Age* (Age of Coal Plants).
- (D) *Age of Reptiles*.
- (E) *Age of Mammals*.

These *Ages* are subdivided into *Periods*, to mark the character of rocks formed, viz: (a) Crystalline Rocks; (b) Primary (1st) Rocks; (c) Secondary (2nd) Rocks; (d)

Tertiary (3rd) Rocks; (e) Quarternary (4th) Rocks.
(See Geologic Section, page 48.)

What Constitutes the Azoic Era?

32. The Earth's interior being very hot, no regular well-defined formation can exist there. As this mass comes in contact with the cooler crust, it crystallizes and takes on a form that permits classification. The word *Azoic* means without life and applies to rocks so highly heated as to make life impossible in them.

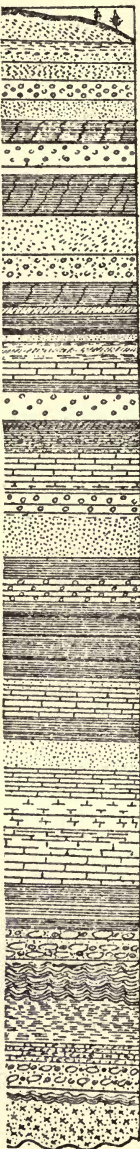
It seems certain that no part of the original crust exists today. Nature's forces have changed and moulded it over and over again in the process of ages. The oldest rocks known today belong to the Azoic Era, such as Granite, Syenite, Gneiss, Porphyry, Talc, etc. The most valuable deposits of iron ore like those of Michigan, Pennsylvania, Alabama, Missouri and Colorado, are found in the Azoic Rocks.

A glance at the Geologic Sketch (page 20) in the front of the book, shows the Azoic Rocks of North America, marked No. 1, on a light mottled background.

Note also the region about Lake Superior, the richest iron and copper region of the world, is in these ancient rocks. North of the Great Lakes this formation extends northeast to the Atlantic, thence southwest into the United States along the Appalachian mountains.

The Azoic Rocks are devoid of both animal and vegetable fossils, and are classed as crystalline, being very favorable for deposits of metals and minerals.

Geological Section Western North America

ERA	AGE	SECTION	PER- IOD	FORMA- TION	CHARACTER OF ROCKS			
Azoic (Without Life)	MIND		RE- CENT	SOIL	Alluvium, Clay, Pebbles, Conglomerate, Etc.			
			Quarter- nary	Glacial				
			Cenozoic (Recent Life)		Tertiary Rocks	Plio- cene	Basalt, Andesite, Lava, Sandstone, Shale and Clay.	
						Mio- cene	Rhyolite, Volcanic and Granite Detritus.	
						Eo- cene		
			Mesozoic (Middle Life)		Secondary Rocks	Cretacious	Soft Sandstone, Shale, Lime- stone, Lignite Coal, Fire- clay, Etc.	
						Jura-Trias	Trap Rocks, Limestone, Quartzite, Conglomerate, Metamorphic-Sandstones, Eruptive Granite.	
					Primary Rocks	Carboniferous	Blue-Limestones, Gypsiferous Shales, Bituminous Coal Beds, Grit Conglomerates, Etc.	
						Devo- nian	Magnesian Limestone, Red Sandstone, Shale, Etc.	
			Paleozoic (Ancient Life)			Silu- rian	Limestone, Hard Sandstone, Dolomite, Shale, Etc.	
						Camb- rian	Slate, Quartzite, Hard Sand- stone, Marble, Etc.	
No Fossils		Crystalline Rocks	Archian	Gneiss Mica-Schist, Quartzite Granite, Porphyry, Syenite, Etc.				

What Marks the Paleozoic Era?

33. Refer again to the Chart, page 48, and note that this Era is divided into ages known as Cambrian, Silurian, Devonian and Carboniferous. The names of these subdivisions have been given them to mark the changes in animal and vegetable life—as evidenced by the fossil remains.

Cambrian Age. This takes its name from Cambria, the Latin for Wales, where the rocks lying next to the crystalline were first noted. It is also called "Lower Silurian" by some Geologists. The first distinctive animal fossils appear in the Cambrian Age.

The rocks the Cambrian Age began to form from the sediment or muddy waters into shales. These with added pressure and heat were changed into Slates. Quartzite made its appearance. Limestones were crystallized into marble. The Cambrian formation extends along the eastern base of the Appalachians. It crops out at various points west of the Missouri River. The Lead-Zinc ores of Illinois, Wisconsin and Missouri are found in the limestones of this period. Volcanic disturbances in the region of Lake Superior tilted up the primitive rocks and formed a bed for the Lake. Fissures there formed were filled with native copper, the richest in the world.

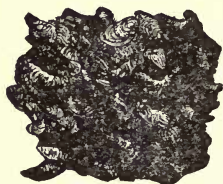
The Black Hills of Dakota, and sections of country west of the Rockies also belong to this period. Next to the Azoic rocks, those of the Cambrian are the most favorable for minerals, especially when intruded by Eruptive Rocks.

No land animals had yet appeared, but the seas swarmed with coral insects during this period.

What Distinguishes the Silurian Age?

34. This also takes the name from a tribe of Britons, called *Silures*, where the formation was first discovered. The salt beds of North America were formed in this period,

Fig 9.



Fossil oysters.

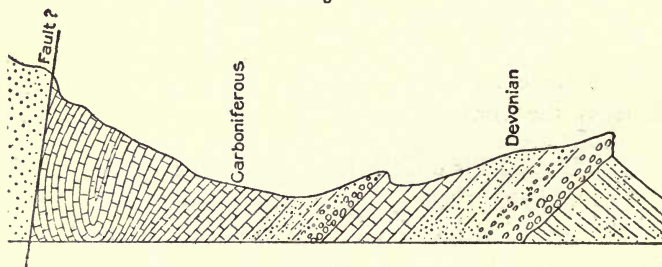
due to the evaporation of ocean water that formerly covered the land. Magnesian Limestone (Dolomite) and hard compact Sandstones make their first appearance. The Silurian Age is known as the "Age of Mollusks," those soft bodied animals having shells like oysters, whose fossils are well preserved in many of the rocks of this Age. (See Fig. 9.)

Some important mines in Arizona and Nevada are found in rocks of this age.

How Can We Tell the Devonian Rocks?

35. This Age takes its name from Devon, England, where the formation is clearly developed. The rocks of this

Fig. 10.



Ideal section illustrating structural relations southeast of Fort Bowie, Ariz.

age are red sandstones, shale, slate and magnesian limestones. It is also called the "Age of Fishes," the fossils of which first

appear. Vegetable fossils, flags, rushes and shrubs are also noted. A good portion of the Ohio Valley was covered with dense marshes, and climatic conditions were such as to produce a very rank growth of vegetation during this and the preceding Ages.

The rocks of this period carry ore bodies in connection with intrusive sheets of porphyry. (See Geological Sketch.)

What Is Known of the Carboniferous Age?

36. This Age is so named from the abundance of coal formed in its times. The element carbon forms the framework of all plants. When vegetation dies and remains exposed to the atmosphere, it decomposes, rots as we commonly say, and forms vegetable mould or soil. However, when vegetation is covered up and removed from the action of the air, it is preserved, and when accumulated debris makes pressure great, the water is squeezed out and it forms into the mineral we call coal. The longer it is buried and the greater the pressure, the better the coal. The peat bogs today are simply Coal in the first stages. (See Fig. 11.)

Fig. 11



A fragment of coal bearing the impression of a fern-leaf.

Scientists conclude that the presence of large amounts of carbonic acid in the atmosphere and the combined heat of the sun and the earth's crust, tended to produce a dense tropical growth.

No air-breathing animal had yet appeared as they could not exist in such an atmosphere, laden with the deadly carbonic acid. An all-wise Providence seemed to have had two objects in view,—

first to purify the air by the growth of very dense vegetation, and second to store away fuel for future generations of men.

The North American Continent, that had been rising slowly from beneath the sea, now began to sink, carrying along the dense vegetable growth of preceding ages. Sedimentary matter, from the heights was washed down covering it deeper and deeper until the buried vegetation was thousands of feet beneath the sea.

The principal coal beds of North America had their origin in the Carboniferous Age. An idea of the vegetable growth may be had from the thickness of the Mammoth Coal Vein in Pennsylvania of thirty feet and a vein of coal in Nova Scotia 40 feet thick. This coal underlies sandstone mainly, and as this is known to be an aqueous or water rock, we have additional proof that this coal was formed by buried vegetation.

In Western North America, this Age is marked by gypsum shales and blue limestones. The western coals, especially the softer varieties, were not formed until a later period. The Carboniferous rocks are not favorable for metallic ore bodies.

What Characterizes the Mesozoic Era?

37. *Mesozoic* means middle life, which began a new cycle in the Earth's history. A higher order of animal, the reptile, now appears, the fossils of which distinctly mark the dividing line between this and preceding age. The *Mesozoic* is usually divided into three periods, viz:

(1) *Triassic* (Triple), so named from three distinct groups found in Germany.

(2) *Jurassic*, so named from the Jura Mountains in Switzerland.

(3) *Cretaceous* (Chalk).

The first two are not distinct in North America, so are usually classed under the compound name Jura-Trias. During this age the Carboniferous area is again uplifted from its long burial under the seas. The central portion of the continent was pushed up; rock making advanced towards the Atlantic on the east, the Gulf on the south and towards the Rockies on the west.

In the old world, during this period, the salt deposits of England, Poland and Spain had their origin. In North America this period was characterized as one of violent upheavals and perhaps terrific convulsions of nature, causing such stupendous mountain ranges as the Sierras to be lifted above the interior sea. Everywhere trap dikes and ridges attend this formation. The proof of this is that the adjacent sandstones were baked by heat, the layers uplifted by escaping steam and the fissures often filled by crystallized minerals. The Gold-bearing rocks of the Pacific Coast are in what is known as the Jura-Trias Belt, extending from Alaska to Central America and having a width of 300 miles in places. These rocks are found as far east as the Rockies, but are not so distinct as in the Sierras.

During this period such giant fissures as the Mother Lode in California were formed and filled with mineralized matter. These fissures generally follow the trend of the mountain ranges or run parallel thereto. The cross-veins are of a later period and not so well mineralized.

What Peculiarity Has the Cretaceous Period?

38. This period takes its name from *Creta*, Latin for chalk, and hence is called the Chalk Period. It is very distinct in the Old World. In North America, however, the formation is a mixture of chalk and sand, forming what are called soft sandstones, many of which can be dug out of the earth with a spade and rubbed to pieces in the hand.

The presence of the same fossil shells, as the chalk formation of England and France, serves to identify it as belonging to the same Cretaceous period.

Lignite (Wood) coals of the Rocky Mountain and Pacific Coast as well as the Quicksilver deposits of California, are all found in the Cretaceous rocks. This formation extends along the eastern base of the Appalachians from New York to Mississippi; from Texas northward along the eastern base of the Rockies, and in places extending across their slopes as well as along the western base of the Sierras. The rocks of this period are not good ore bearers, but are more noted for Coal and Oil.

What Is the Cenozoic Age?

39. Previous to this era all animals lived in the water. A new order of animals now appear, which suckle their young, hence it is called the "Age of Mammals." The fossils of forest trees first appear in the rocks of this age.

In the Old World, this era is divided by Geologists into several periods, but these distinctions are not clearly defined in North America, hence these will be classed under the common names of Tertiary (Third) and Quarternary (Fourth) Periods.

Tertiary Period

40. A glance at the Map (Fig. 12) will show Geological conditions as they appear in this period of North America. The white shows the land, and the shaded portions, the continental crust still covered by water.

Fig. 12



Map of North America in the Tertiary Period

Small veins of lignite coal were formed during this period, but they are of little importance. No great mountain uplifts occurred as during the Jura-Trias period. The older rocks underwent a change (Metamorphosis), that is the igneous rocks were decomposed and formed into sedi-

mentary rocks, while some of the stratified rocks were metamorphosed by pressure and internal heat. What is called Conglomerate Rock, composed of igneous and aqueous rocks, pebbles, etc., were cemented together with lime matter during this period. The formation of shales and clays also continued during this period. Many mountain valleys received a top-dressing of vegetable detritus from adjacent hills, forming arable land.

The most distinctive feature of this period was the formation of *Basalts* and *Rhyolites* from successive flows of igneous matter from the interior of the Earth.

Nevada was the scene of great eruptions. As many as fifteen distinct flows of Rhyolite have been noted and classified by the United States Geological Survey. Andesite intrusions are also of this period, all of which, associated with the older rock formation, tell a story of volcanic activity without a parallel in the earth's history.

The igneous formations of Cripple Creek, Colorado, Clifton and Bisbee, Arizona, belong to the Tertiary eruptions. They are generally remarkable as ore producers.

What Changes Occurred in the Quarternary Period?

41. The close of the Tertiary Period saw the Earth to all appearance ready for man, but the whole upward process was now reversed. The long tropical summer was followed by a dismal winter that geologists believe lasted for thousands of years. This period has been previously described under Glacial Age, and was probably due to an uplift of the Arctic crust causing the Polar icebergs to drift southward and cover the North American Continent east of the Rockies.

The one distinctive crust change in this period was the grinding and polishing of the surface rocks into pebbles and

boulders, the forming of a successive line of terraced beaches and the filling of low basins with silt alluvium, clay, etc., to form a garden spot for man.

The fossil bones of primitive man and his rude stone implements are conclusive evidence that when the Glacial drift receded, man came upon the scene. This accords with the Mosaic account of man's creation on the sixth day or period, so that Geologic and Sacred History do not conflict in the "Days of Creation."

What Practical Mining Lessons do the Geologic Ages Teach Us?

42. Two things stand out clearly as a result of our tracing the changes that have taken place in the Earth's crust:

(1) The Sedimentary, or water formed rocks, do not contain metallic minerals of use to man in sufficient quantities to be extracted with profit. It is true that gold is found in placer beds where nature has concentrated it from the mass of detritus washed down from the heights, but the regular sedimentary rocks such as sandstone may usually be regarded as "barren" and the practical miner may well ignore water-formed rocks in mining explorations.

(2) The Igneous (Fire) and Metamorphic (Altered) Rocks only are associated with metal mineral deposits, the reason for which may not as yet be clear, but this will be fully explained under the subject "Ore Deposits."

What are the Three Zones in the Earth's Crust?

43. We have traced the earth's history by strata and fossils from the beginning down to the present, and it now remains to consider the crust with reference to its physical

and chemical condition, as a result of the Geologic changes due to heat, moisture and gases.

It has been proven that the Earth's interior is intensely hot, increasing from the surface downward, and this fact taken in connection with the action of water, gases and pressure, produces fairly well defined crust-belts which are known as *zones*.

The principles involved in these changes cannot be considered here, and only a general statement as to the existence and condition of these Zones will be attempted at this time.

Surface rocks, being formed from sediments, are more open and porous than the deep-seated rocks of the same, or different materials. The weight of the mass above compresses them and forces out the air and water from the open spaces, making a close-grained rock. Such rocks filling deep depressions, tend to produce a solid crust which the eruptive forces do not fracture easily. The elevated regions, having been pushed up from below, through the weaker portion of the crust, are necessarily more fractured and broken up than elsewhere. This condition favors the formation of mineral veins and ore deposits, and it is to such sections of the crust that the term *zone* more particularly applies.

The Three Zones

These belts are known under the following names, viz :

- (1) OXIDE, or Fracture Zone.
- (2) SULPHIDE, or Fracture and Flowage Zone.
- (3) MOLTEN, or Flowage Zone.

(See Illustrations, Part IV, Fig. 47.)

What Characterizes the Oxide or Fracture Zone?

44. This zone is also called the *Weathering zone*, because

of the influence of atmospheric agencies on the exposed rocks.

It begins at the surface and extends downward to the permanent water level, which varies in different localities from a few feet to the depth of a mile. In the *Oxide zone* the rocks are under moderate pressure from above and when forced to move by internal convulsions, they break easily, causing cracks or fissures in many directions. Owing to these fractures it is usually impossible to quarry rocks of any size for building purposes. Often rocks that appear sound, when handled or subjected to pressure, show their hidden defects. This broken up condition results in many cavities or open spaces, into which the gases of the atmosphere and the water from rains and melted snows find their way, resulting in a process called oxidizing, or weathering. The general effect of this process is to disintegrate the parts of the rocks exposed and carry their heavier particles into larger cavities or veins, rendering the rocks still more open and porous.

What Distinguishes the Sulphide or Fracture and Flowage Zone?

45. This Belt has a distinct line separating it from the Oxide Zone, in the permanent water level, from which it extends downward to the depth of about four miles. This is also called the Zone of Cementation, because the cracks or fissures due to Earth movements have a tendency to cement together much as a crack in the human skin heals over by natural processes. The cementing material is furnished by the disintegrated rocks from the Zone above.

In this Zone the open spaces and cavities are relatively small decreasing in size with depth. The rocks of this Zone are continuously being fractured by the eruptive forces, but by the pressure of the mass above and the circulation of warm

waters charged with sedimentary material from the Oxidized rocks above, such fractures are rapidly repaired and cemented together again.

In the Sulphide Zone, the more rigid rocks like quartzite may fracture, but weaker rocks like clay bend and fold over like wax, causing all cracks and cavities to rapidly disappear.

What Do We Know About the Molten or Flowage Zone?

46. There is no distinct line separating the *Flowage* from the *Sulphide zone*, as they blend readily into each other. No shaft has ever penetrated the Flowage Zone, hence its existence is largely theoretical. From the known increase in temperature with depth, we are reasonably certain that a point would be reached in which the plastic or molten state due to internal heat, taken in connection with the great pressure from the mass above, would make fractures improbable and only hair-like openings could exist.

The existence of the Flowage Zone is generally recognized by Scientists. It is believed to begin immediately under the Sulphide Zone, and extend downward from three to six miles.

Such a molten mass would rapidly change form like wax. The great heat would prevent any surface waters from remaining in this Zone, and if they did descend to this depth, would immediately be changed into vapor and rise to a cooler Zone.

The conditions in this Zone are favorable to the formation of heavy silicates, quartz, feldspar, serpentine, etc., from the disintegrated primary rocks.

The heat in this Zone is doubtless sufficient to change many metals to a gaseous state, and these metallic vapors

arising are deposited in the gangue matter of previously formed veins, which process is more fully explained under "Ore Deposits."

Below the Molten or Flowage Zone, the materials are believed to be in that fused condition, to form the Igneous rocks we find spread out on the surface today. All metallic substances, there existing, would possibly Volatilize and find their way upward through fissures, filling and mineralizing existing veins.

How to Use Geological Survey Maps and Reports

47. The United States Government recognizes the value of Geological information to the miner, and it is for his benefit largely that this valuable department is maintained.

A Geologic and Topographic Atlas was authorized by law in 1882, and about half of the United States, including Alaska, has already been mapped.

These maps are arranged in what are called Quadrangles bounded by certain meridians and parallels, and designated by the name of the principal town or prominent natural feature within the quadrangle. About 1800 of these sheets have been engraved and printed, and they may be obtained at a price of 25c each.

No mining man should be without a Geological Map of the district in which he is interested.

In addition to these maps, the Department issues bulletins on mineral resources, and special Annual Reports on various subjects of interest to the mining man. Many of these Department papers may be had simply for the asking, and the author advises every reader to write to the U. S. Geological Survey Director, Washington, D. C., for a list of the

various publications, from which such may be selected as will be of special interest to you.

Many States and several foreign countries now maintain Departments for collecting and disseminating information in the interest of the mining industry and such documents may be had by applying to the proper authorities.

The United States Government has recently recognized the importance of a knowledge of Geology to the mining man by appointing the Director of Geological Survey to the head of the new Department of Mines.

The Government is anxious to serve you, and you owe it to yourself to take advantage of everything so freely offered.

PART II

PETROLOGY

Part II

PETROLOGY

We have heretofore treated Rock as a general mass, forming a part of the Earth's crust, but we shall now consider Rock as a specific material, belonging to certain classes or groups, each having its own peculiar composition and structure.

What is Rock?

1. The term Rock as used by the Geologist, includes not only the stony matter familiarly known as Rock, but also all massive mineral substances which go to make up the Earth's crust.

This would include sand, pebbles, clay and soil, as well as the same materials consolidated into hard stones. The terms Rock and Stone are generally used to mean the same thing, but a strict use of the word Stone implies a rock that has been shaped or cut, as a precious stone or building stone.

What is Petrology?

2. The word Petrology as used by later Scientists is derived from the Latin *Petra*, meaning Rock, and *Logos*, study, so the word means literally rock-study or rock-science.

Of What are Rocks Composed?

3. Rocks may be classed according to their composition as follows:

- (1) Silica.
- (2) Alumina.
- (3) Lime.
- (4) Silicates.

The last named has silica as its principal constituent, and the Alumina Rocks are also forms of silica, so we may reduce all rock masses down to two general classes, called Calcareous and Silicious Rocks.

What are Calcareous Rocks?

Fig. 13



Calcareous crystals.

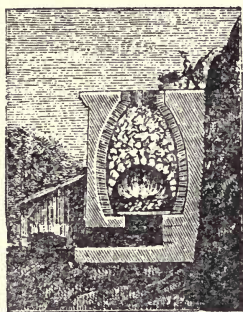
4. The word Calcareous is from the Latin *Calx* (lime) and the adjective ending *ous* means composed of, so that a Calcareous Rock is principally composed of lime, though most all such rocks contain some silicious matter.

The common calcareous rocks include chalk, lime-spar and marble, and they are called Carbonates because of the Carbonic acid they contain, which serves to distinguish them. When calcareous rocks are burned in a Kiln, the acid is expelled and leaves pure lime, called Oxide of Calcium. (See Fig. 15). When any of the common acids are placed on Calcareous stones, they fiz or effervesce, like soda-water, due to the escaping carbonic acid gas. Even vinegar, which is a fruit acid diluted with a large percentage of water, when placed on a lime rock, will cause it to fiz. Lime rocks are nearly all soft and can be scratched with a nail or knife and this fact serves to further identify them.

What is the Origin of Calcareous Rocks?

5. If we examine a piece of chalk with a good microscope, we find it composed of minute shells, which proves that chalk is simply a consolidation of animal fossils. Animals have the power of secreting lime from the water in which they live. Even when lime rock contains no visible fossils, it is possible that the sea has ground the shells and

Fig. 15



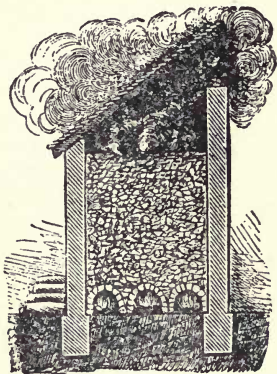
Lime-kiln. When calcareous stones are subjected to a very high temperature they are transformed into lime.

Fig. 14



Crystal of Gypsum.

Fig. 16



An oven for burning plaster. Gypsum subjected to a great heat becomes plaster.

corals into fine powder which settles out forming sedimentary lime rocks. When such lime sediments are brought under the influence of heat and pressure within the earth, they crystallize into Calcite (calc-spar) and marble, which action destroys the original fossil shapes.

We have seen that in the Cretaceous Age, vast strata were formed so that it was known as the Chalk Period. From the vast amount of lime rock in the world today an idea may be formed of the animal life that must have existed in past ages.

How Do Limestone and Dolomite Differ?

6. Magnesian Limestone is called Dolomite. The magnesia in it makes it harder than Limestone and it will not effervesce in ordinary acids, unless heat is applied, and these two facts make it comparatively easy to distinguish between Limestone and Dolomite.

What is the Composition of Marble?

7. Marble is crystallized limestone and its origin is due to the solution or the fusion of limestone, which in cooling and precipitating forms into a crystalline structure. When clear-marble is broken, the fine grains or crystals show like loaf sugar. The various colors of marble are given it by iron and other impurities. Ordinary fruit acids like vinegar or lemon juice affect marble, while the stronger acids cause it to effervesce. The acids of the atmosphere slowly decompose marble, so while very pretty, marble will not endure like granite or sandstone.

What is Gypsum?

8. This is also a Calcareous rock, but it contains sulphur chemically combined, hence is called Sulphate of Lime.

Gypsum is only slightly affected by acids, owing to the sulphur content. It is softer than Calcite, and these two points will usually serve to distinguish Gypsum from ordinary Lime rock. (See Fig. 14).

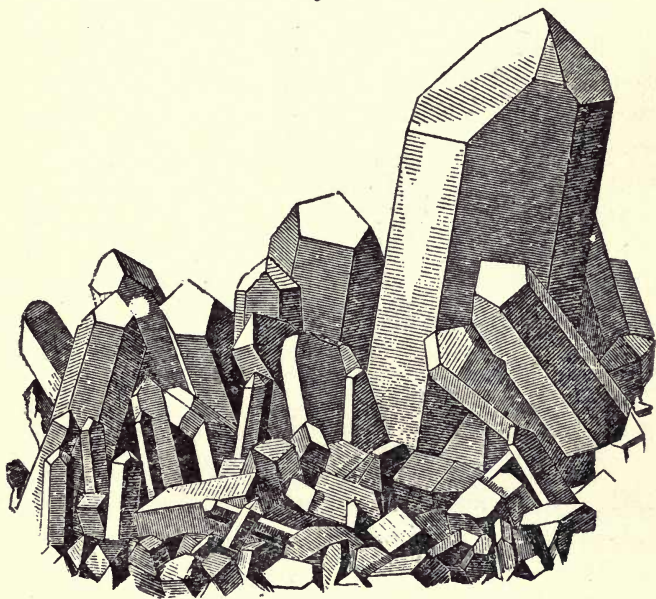
There are two forms of Gypsum: That crystallized in fibrous masses of pearly luster is called Satin-Spar; when it appears in scale layers and crystals, it is called Selenite, which if snowy white and solid is called Alabaster. When Gypsum is burned the sulphur is driven off, leaving what is known as Plaster of Paris. (See Fig. 16.)

The Uncrystallized Gypsum, ground into white powder, is sold as plaster for fertilizer, also used in the manufacture of Portland Cement.

What are Silicious Stones?

9. The word Silicious means composed of Silica, but do not understand they are composed wholly of silica. As a

Fig. 17



A Cluster of Quartz Crystals from Lake Superior.

matter of fact many silicious stones contain some calcareous matter. A familiar example of Silica is quartz, which is called an oxide of silicon made up of Oxygen,—a gas, and silicon—a solid. Quartz is so hard that it strikes fire with

steel and will scratch glass, but cannot be scratched with a knife. It breaks into irregular fragments which have a glassy luster. Quartz is generally a fire-formed rock, and in cooling it arranges into crystals, sometimes very large, but many quartz crystals require a magnifying glass to make them plain to the ordinary observer. (See Fig. 17).

The Silicious stones are the most plentiful form of rock and make up more than half the Earth's crust. Flint and pebbles are the most common silicious stones.

Silica is *insoluble*, that is it cannot be dissolved by common acids, and is *infusible* alone, that is, cannot be melted except by using a flux.

There are many forms of quartz, known as Pink, Smoky, Milky, Granular, etc. The latter when powdered is used for making sand paper, glass and pottery. Silica when powdered and air-floated is used as a body for paints, used at first as an adulterant, but now known to stand the weathering action equal to lead paints. The Amethyst, Chalcedony, Agate and Jasper are Precious Stones composed almost entirely of Silica, and the distinctive colors are due to the presence of other elements as impurities.

What is the Origin of Quartz?

10. As already stated, quartz is a compound of silica and oxygen. It is not a native rock, and occurs principally in veins. The deepest seated rock is Granite, which is nearly three-fourths silica. It is believed that the heat and pressure of the Flowage Zone previously described separates out the silica from the primitive rocks and the eruptive forces project it upward, through fissures into the Oxide Zone, where it combines with the oxygen there present, forming what we know as quartz, filling veins for the reception of metallic

minerals. Quartz has been well termed the "Mother of Gold," since it forms the universal matrix, or shell covering

gold. However, Quartz is not always mineralized, but often occurs in dykes, in the older formations, perfectly "barren" of any metals, sometimes called "Bull Quartz."

Quartz is also found in many places where ledges and veins do not appear, so it would appear that there is another source of origin.

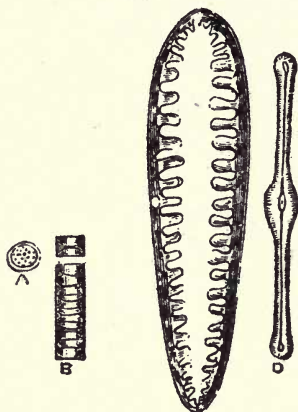
It is quite probable that most of the Flint and Horn-stone is of animal or vegetable origin. Sponges are known to secrete little points of silica from the muddy sea bottom.

DIATOMS are little one-celled organisms, too small to be seen with the naked eye, yet when gathered into countless myriads they appear as a silicious slime. They have the power to separate the silica from the sediment, and when these diatoms die their silicious framework form strata of great extent and thickness. This is also the origin of what is called Tripoli and Infusorial Earth, and the proof of this is that Flint and Hornstone, under powerful microscope, usually show fossils of these animal and vegetable organisms. (See Fig. 18).

What are Silicates?

11. These are compounds of Silica and other elements, as alumina, lime, magnesia, potash, and iron oxides.

Fig. 18



Diatoms from Albany and Waterford, Maine.

B is magnified 25 Diameters.

C is magnified 250 Diameters.

D is magnified 200 Diameters.

FELDSPAR. This is somewhat softer than quartz and breaks in two directions, leaving a pearly flat crystal surface, and these characteristics will generally enable any one to distinguish Feldspar from Quartz.

Fig. 19



Feldspar decomposes easily and when mixed with pulverized silica forms common clay. Pure feldspar sediment forms Kaolin, from which porcelain is made. (See Fig. 19.)

MICA (Micare—to Glisten). Isinglass is a common name for mica. When in large sheets it is used for windows in stoves. Small flakes of mica in rock may be mistaken by the novice for gold, but mica glistens, can be broken easily into scales, or picked out with the point of a pen-knife, and it is often so light as to float, so that no one should ever mistake mica for gold.

Hornblende, Pyroxine, Serpentine, Talc and Chlorite are silicates, carrying Magnesia, Lime and Alumina in varying proportions.

How are Rocks Classified?

12. In our examination of the Earth's crust we found two kinds of rocks, with reference to their origin one formed by fire, known as *Igneous Rock*, the other formed by water, known as *Aqueous Rock*. Fire and Water are two opposing agencies, hence an Aqueous Rock brought into contact with the heat from the fiery furnace within the Earth, undergoes a change so that it partakes of the nature of each, and is then called Metamorphic, which means changed or altered rock.

What are Aqueous Rocks?

13. These are so called from *Aqua*, Latin for water, which deposits sediment from decomposed rocks, forming regular layers, and hence are sometimes called *stratified* rocks.

SANDSTONE is a common form of Aqueous Rock, and is composed mainly of sand, pressed and dried by the earth's heat, so that when deep seated forms a very dense rock.

CONGLOMERATE Stone is made up of pebbles, calcareous and silicious matter, all mixed together in a pasty mass, which is cemented together much as concrete in a pavement or building. Gold and precious stones are sometimes found in a Conglomerate formation, as in the Rand Mines of South Africa.

SHALE is simply clay, dried and compressed so that it splits into thin flakes or laminae.

SLATE is simply shale subjected to long continued pressure and baked by internal heat of the Earth.

What are Igneous Rocks?

14. These rocks are so named from the Latin, *Ignus*, meaning fire, and hence Igneous Rocks are fire-formed. These have been thrown out from the earth's interior, through openings, while highly heated or in a molten state. Igneous rocks are not arranged in layers, and hence are sometimes called Unstratified Rocks. They are sometimes wavy from the flowing molten mass. The Igneous Rocks are arranged in two classes, known as—

(1) *Trap Rocks*.

(2) *Volcanic Rocks*.

What are Trap Rocks?

15. The word *Trapa* is Swedish and means stairs or steps, and Trap Rocks are often found arranged like stepping stones, or in the form of massive terraces or bluffs. Fig. 20 shows a fragment of Basalt, in the shape of a six-sided column. This form of crystallization is common to Trap Rocks everywhere. The Pictured Rocks of Lake Superior, the Palisades of the Hudson, and the Giants Causeway in Ireland, are the most noted examples of massive Trap Rocks. They are very hard, but are seldom used for any practical purpose except in road building. The principal Trap Rocks are:

- (a) Basalt.
- (b) Diorite.
- (c) Porphyry.
- (d) Amygdaloid.

Fig. 20



Fragment
of basalt.

(a) **BASALT.** This is called Dolerite, from Dolerous, deceptive, because the composition is difficult to determine, being mainly Feldspar and Augite. The colors are various but mostly of a bottle green, having small crystal grains.

(b) **DIORITE.** This is also called Greenstone, from its color, the composition being principally Feldspar and Hornblende, the latter occurring in needle pointed crystals.

(c) **PORPHYRY (Purple).** This rock was originally so named from a purple variety found in Egypt, and highly prized. The word Porphyry is now used to designate any Igneous rock containing Feldspar crystals. It appears to be imperfectly crystallized lava and is of much importance to the mining man, as it is closely associated with mineral veins, and ore deposits, though not usually found in the vein itself. (See Fig. 21.)

(d) **AMYGDALOID** (Almond). This is a Trap Rock containing cavities, often filled with Calcite, Quartz, etc., so that a weathered surface appears like a cake stuck full of almonds. (See Fig. 22.)

The general form of all Trap Rocks is that of a column or prism having three to eight sides and a diameter running from a few inches to many feet; such pillars are often left standing several hundred feet high, having the appearance of an old castle ruin.

Fig. 21



Porphyry.

Fig. 22



Lava (Scoria), in part turned into an Amygdaloid.

What are the Volcanic Rocks?

16. There are two common varieties of Volcanic Rocks:

- (a) Trachite.
- (b) Lava.

(a) **TRACHITE** (Trachus—rough). This is so named from its rough, gritty feel. It is of porous open structure and light weight, and has various colors running from white to gray and black. The cones of many extinct volcanoes are formed of Trachite. Rhyolite is a trachite with quartz

crystals, and has many different colors, but generally of rough fracture and often has wavy lines from flowing while in a molten condition.

(b) LAVA. This name is given to all molten matter flowing from Volcanoes. When lava cools, the upper portion of the stream is light and porous, while the under portion cooling more slowly is similar to Basalt. Lava contains Feldspar and Pyroxine and one hundred different varieties have been observed in the eruptions of Vesuvius.

(c) PUMICE stone is Feldspathic Scoria from Volcanoes; it is porous and has slender air-cavities, so that it is sometimes found floating in the ocean.

(d) OBSIDIAN is volcanic glass that has separated out from Lava.

What are the Metamorphic Rocks?

17. We have seen how an Igneous rock may be disintegrated and washed down to a basin to become an aqueous rock. This is a complete change. When a sedimentary rock comes in contact with the intense heat of the earth's interior, it suffers a change, so that it partakes of the nature of both an igneous and aqueous rock, and it is then called a Metamorphic rock. The word Metamorphic means altered or changed, and the principal agencies causing the change are *heat, pressure and moisture*.

For example,—Lava penetrating an aqueous rock would alter its character, the clay be changed into slate, the limestone altered into marble, and earth rock like sandstone be transformed into quartzite or even granite. In this Metamorphic process, the stratification would be destroyed and the fossils partially or entirely obliterated. A metamor-

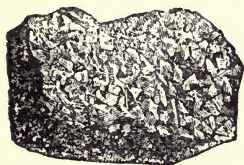
phic rock examined under a microscope will sometimes show a fossil, spangles of metal or mica. Often little nodules or lumps of ironstone enclose imperfectly formed quartz crystals, or garnets may be sprinkled throughout the mass.

There are a vast number of these Metamorphic Rocks, but space forbids more than a mention of a few prominent types.

Granite, What It is and How Formed.

18. We have seen that Granite is an Azoic Rock, lying at the bottom of all formations, yet we find it capping the highest mountains.

Fig. 23



Fragment of granite,
a mixture of quartz, felspar,
and mica.

As a primitive rock, Granite is hard and compact, but as a Metamorphic rock, its most abundant form, it is more or less fractured so that it is often as easily crushed and weathered as Limestone. (See Fig. 23.)

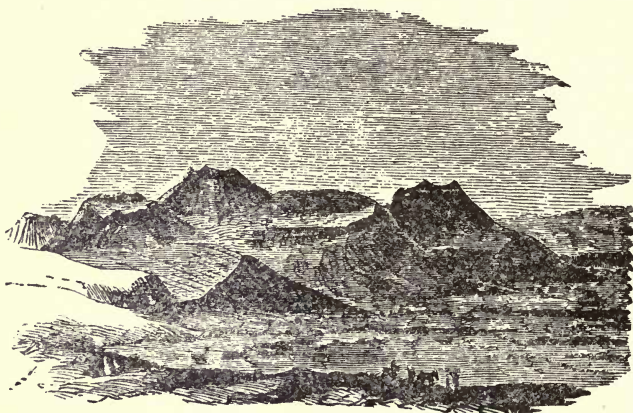
The word is from *Granum*, a grain, and indicates its granular structure. The composition of granite is Quartz, Feldspar and Mica. Metamorphic Granite occurs in veins, hills and masses which were forced up through the crust in a moist, pasty condition and crystallized from contact with the cool atmosphere. Granite is always newer or younger than the rocks it fissures, or through which it has been ejected. The fact that Granite is composed of nearly the same elements as sandstone and clay has led some to conclude that most granite has been formed by a Metamorphosis of the sedimentary rocks. Granite Peaks always appear *single* in well rounded summits, while volcanic rocks like Basalt always appear as *twin* mountains with tops flattened into cones. (See Fig. 24.)

GNEISS (Nice) differs from Granite only in being arranged in layers from pressure and points to the same origin.

MICA SCHIST is a leaf-like arrangement of quartz and mica, the latter probably derived from a decomposition of Feldspar.

SYENITE. This is a Granite in which the Mica is replaced by Hornblende. It possesses great strength and withstands enormous pressure. It is generally grayish in color due to its chief constituents, Feldspar and Hornblende.

Fig. 24



Volcanic Cones, near Mono Lake.

TALCOSE SCHIST is a slate that contains much Talc.

CHLORITE-SCHIST contains the olive-green mineral Chlorite (resembling Talc) together with slate and clayey shale. It is usually associated with gneiss.

How Do Rocks Differ in Structure?

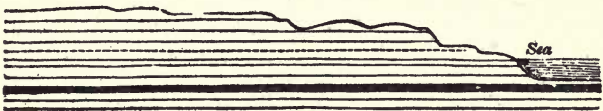
19. With reference to the structure, rocks are either:—

(1) Stratified Rocks.

(2) Unstratified Rocks.

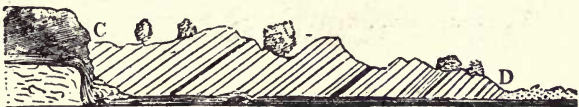
.. STRATIFIED ROCKS. When the earth's crust was lifted up and dry land was formed, it began to erode under the ceaseless action of rains, winds and water, the debris being carried down to the basins where it was deposited in flat layers as shown in Fig. 25. If it had not been for eruptions

Fig. 25



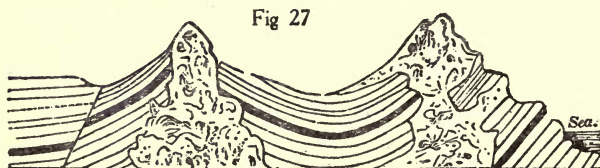
of igneous rocks and uplifts of the crust, these rock strata would have remained just as formed and it would have been impossible for us to read the earth's history as we now do, by strata and fossils. The rocks of the crust have not been penetrated by man more than a mile in depth in a perpendicular line, but fortunately we are able to examine the stratified rocks without descending into the earth, by reason of their

Fig. 26



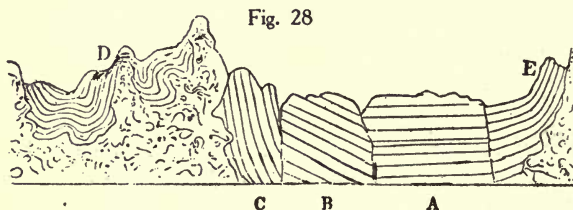
being tilted up on the edges. If we follow a deep chasm like the Grand Canyon of Arizona which is about a mile deep, the successive strata and formations are easily observed. So in following a river course in mountain regions, where there are numerous waterfalls, the rocks representing the successive ages previously described may be plainly observed, the older

strata below and the younger at the higher points, as seen in Fig. 26. The layers that have been exposed by the action of running water are called the "Outcrop." Where the formations have simply been tilted up, the exposed edges, originally formed one uplifted wall of a fissure, while the other wall may have remained stationary, or even sunken.



A curious result of changes in stratified rocks by the intrusion of Igneous rocks from below is seen in Fig. 27. The dark strata lines in the different sections were originally flat as in Fig. 25.

You will notice the igneous rocks forced through and



overlying the stratified rocks at the highest points. This illustrates the origin of hills and mountains, the sections of stratified rocks remain more dense and compact, while the igneous intrusions are more open and porous, serving as chimneys and funnels to let out the heat and vapors of the furnace beneath and making conditions favorable for the formation and the filling of mineral veins.

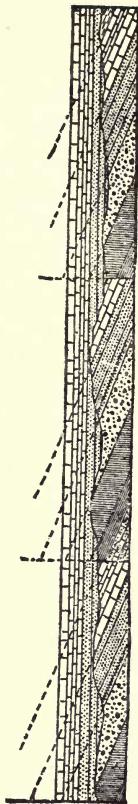
What are Strata, Formations and Groups?

20. One or more layers of Sedimentary rock are called a STRATA. Several strata of such rock, deposited during the same period as shown in Geological Section (page 48), make what is known as a FORMATION. When formations and the strata included are similar, they are called GROUPS.

Strata are said to be *Horizontal* when laid down by water-level as at A in Fig. 28. At B the strata is said to be *Inclined*. At E strata is said to be *Tilted Up*; and the angle formed is called the "Dip"; C is *Vertical* and D *Contorted* (Twisted). An *Anticlinal* is formed by strata looped at the upper end, the lower end of loop or trough is called a *Sincline*, as shown in Fig. 29; where strata are cut through by water it is called an *Escarpment*, or Bluff as at E. When strata are arranged one above the other as at O they are said to be *Conformable*.

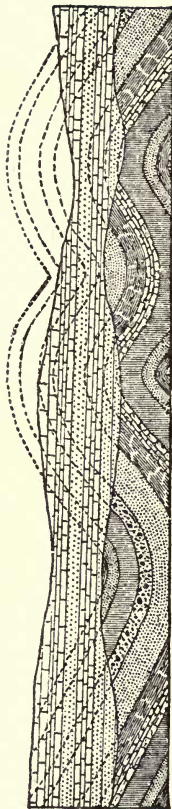
In Fig. 30 is shown strata said to be *Unconformable*, the uplifting and faulting of the older strata was followed by a period of "weathering" which wore off the tilted edges. Later the strata sank and was covered by water, which deposited sedimentary matter in horizontal layers, as seen in upper portion of Fig. 30. An Ideal Section of true *Unconformity* is seen in Fig. 31. The ancient strata were uplifted while in a plastic state, forming bends and folds; the crust was later submerged under the seas, the Anticlinals were worn off and new stratified rocks laid down as shown in the upper part of the Figure leaving the older rocks unchanged, and making what is sometimes called *Diverse Stratification*.

Fig. 30



Theoretical diagram showing how a "discordance" sometimes results from the uplifting and "faulting" of the older strata, followed by a period of atmospheric "denudation," then a submergence and deposition of later sediments.

Fig. 31

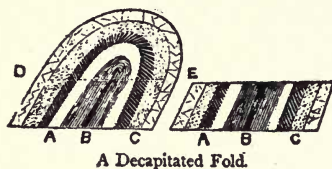


Ideal Section of a True "Unconformity."

The series of strata represented in the lower half of the figure were, after the deposition of the entire series, bent into mountain folds and raised above the sea, after which the resulting land surface was deeply denuded, and the whole area was then depressed again beneath the sea, to receive the undisturbed strata represented in the upper half of the figure.

What are Folds?

Fig. 32.



21. When rocks are young and somewhat plastic the eruptive forces within the earth produce elevations and depressions in wave-like arrangement, instead of producing cracks and fissures. (See Figs. 28 and 29.) Rocks folded in this manner have their upper folds (anticlines) worn off by erosion and the strata then appear standing on edge and parallel to each other, as shown in Fig. 32. To the left is shown a Fold, and at the right is the same after it has been eroded. B is the lower or older strata in the fold, but after erosion B appears under A, and gives the appearance of being older, because the conditions appear reversed. This sometimes occurs in veins, and the inexperienced miner will often conclude that there are two parallel veins when the two parts are simply an anticlinal worn off by erosion, and really one vein.

Fig. 29

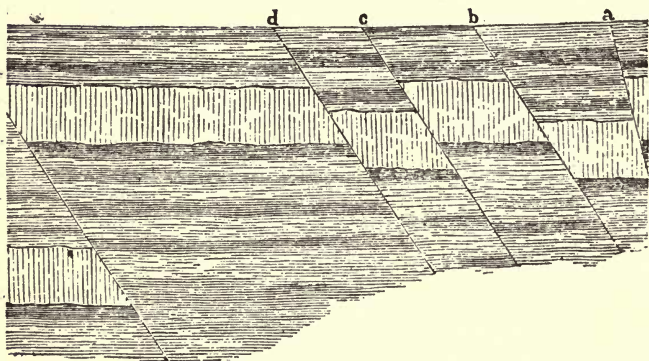


What are Faults?

22. Cracks and fissure in rocks are very common. They are called Faults, because they are imperfections,—that is, unnatural. After stratified rocks become firm and rigid by compression and heating, they no longer bend and fold, but crack and break across the grain by unequal strain from beneath. One side of the strata may be forced upward, the

other wall may remain stationary or slip downward. This produces what are called dislocations, somewhat like a joint out of place in the human body. A series of Faults or offsets are shown in Fig. 33 shown at a, b, c and d. These

Fig. 33



Faults (offsets) in Mt. Pleasant Iron Mine, Rockaway, N. J.

Faults are seldom perpendicular, but the Faults are frequently parallel and the structure is said to be *Jointed*.

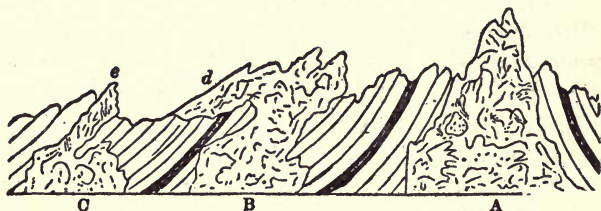
What are the Unstratified Rocks?

23. The Unstratified Rocks are found as shapeless masses underlying, overlying and sometimes penetrating the sedimentary rocks. The Stratified rocks record the Earth's formation period, while the unstratified rocks record the Earth's convulsions.

The Stratified Rocks are water-formed, while the Unstratified Rocks are fire-formed. Molten matter is liquid, and when a liquid cools and becomes a solid, like elements are attracted so that they separate out and form into crystals. It is thus that the Unstratified Rocks are formed, and hence they are also known as Crystalline Rocks.

The six kinds of Crystals in minerals have been noted and classified, which are fully explained under Mineralogy. The natural position of crystalline rocks is in the Earth's interior, in the Fracture and Flowage Zones, inasmuch as their origin is due to the fused mass below. In the molten state there can be no crystals formed, and it is only when such matter is forced up into the cooler Zones that crystals take form. Crystals are also formed by precipitation (throw-down) from liquids, so crystalline rocks may be the result of both these agencies.

Fig. 34



When the unstratified rocks are forced up through opening in the crust they often fill fissures spread out and overly the surface Sedimentary Rocks.

Fig. 34 illustrates the principles named. At c is an underlying Crystalline rock; e is a stratum forced up between Sedimentary rocks; d is a mass pushed up through a fissure and overlaps the Aqueous rocks; a is an igneous mass thrown up as a mountain peak, disrupting the regular rocks and leaving them tilted up.

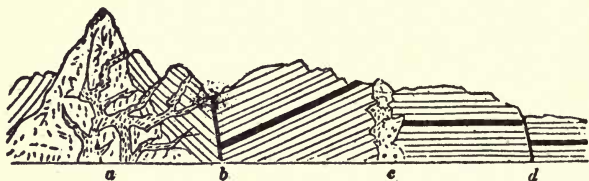
What are Dikes and Veins?

24. We have seen that a Fault is a crack in the rocks, and a later movement of one or both walls displaces the strata, but Faults leave no permanent openings. When a

crack remains open, gases escape through it. Later movements increase the size of the fissure, while the eruptive forces drive igneous matter upward, spreading the walls apart, and it is thus that Faults become fissures, and when filled with crystalline matter may become Veins.

DIKES are fissures filled with igneous matter pushed up from below. Dikes differ from Veins in being formed at one eruption of a uniform igneous mass, while Veins usually have several kinds of filling, the result of a number of eruptions; often the minerals are arranged in bands. Dikes are usually larger than Veins and the walls are more nearly parallel, and seldom branch or form into systems like Veins. The word Dike means a wall; the volcanic filling is always harder than the adjacent rocks, so yields slowly to weathering forces. For this reason Dikes often stand out prominently so that they can be traced easily. In Fig. 35, c, is a

Fig. 35



Fault in the rocks and being filled with igneous rock, becomes a Dike; at a, is a series of Veins traversing both stratified and unstratified rocks.

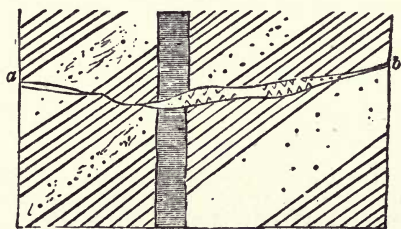
What is the Origin of Veins and Dikes?

25. In drying and cooling the crust contracts and this shrinking causes cracks or openings of various sizes. As in the human body nature collects material to heal, or cement together such fractures. Some openings are filled with

igneous matter ejected from below, which cool and crystallize; we know this by the burning and scouring of the wall rocks of fissures and by the marks (stria) cut into the wall rocks, by the upward movement. In many instances Dikes passing through strata of Lime or Chalk, form Marble. Some fissures are filled by dissolved matter from adjacent rocks, which process is more fully explained under subject "Ore Deposits."

When Veins or Dikes cross or fault each other, as is not uncommon, the respective ages of each are easily told. The older is always cut by the younger or newer formation. This principle becomes important in mineral Veins, as the younger veins are usually a less important source of minerals.

Fig. 36



Dike.

a b. A Quartz Vein passing through a Greenstone Dike and Layers of Gneiss.

In Fig. 36, we have a Quartz Vein(ab) passing through a Greenstone Dike. Here we know the Quartz Vein is younger than the Dike and the adjacent rock, because it cuts and continues through each. Had the Dike been younger or later formed, it would cut off the Quartz Vein.

Veins are not confined to regular fissures in rock formations. Large rocks wholly disconnected from fissures often have seams which have been filled by matter crystallized out

of adjacent rocks. These clefts are usually mended with the strongest materials at hand, from highly heated water charged with mineral matter.

Fig. 37



Vein-form Pebble from Driit, Elmira.

Granite eruptions are frequently found with many rocks filled with Quartz or Feldspar, and the finest seams are filled with crystalline matter, deposited originally in a pasty material, showing nature's process of repairing rock fractures. (See Fig. 37.)

PART III

MINERALOGY

Part III

MINERALOGY

Introduction

1. We have learned that the Mineral Kingdom (see page 31) includes every form of matter not Animal nor Vegetable and that when life ceases in the animal and vegetable, they too return to their original mineral substance. We have also seen that the term Rock in a general sense covers every form of mineral matter, having no reference to the composition or proportion of the combined substances, but we shall now regard a mineral in a particular sense.

What is a Mineral?

2. A MINERAL is a distinct kind of rock, and may be either a single substance, as Gold, or a combination of substances, as Quartz, which is made up of two elements, Silicon and Oxygen, not merely mixed together, but united in certain fixed proportions of each constituent.

How are Minerals Formed?

3. It has already been explained that Crystalline Rocks are formed within the earth largely by igneous action. Minerals are the highest form of crystalline rocks and their origin is due to the union of certain substances which separate out of the mass and combine,—not in a haphazard way, but in strict accordance with natural laws. When these combined substances are forced up into the cooler crust, by

the eruptive forces, they crystallize and take on that definite form, composition and structure known as minerals. The proof of this is, that many minerals may be formed in the laboratory. For example, if we take two substances, sulphur and iron filings, in the proportion of four grains sulphur to seven grains iron, add warm water, soon the mass begins to swell, turns blackish and forms a new body, neither iron nor sulphur, which is called Iron Sulphide. This is a common earth mineral and since nature's laws are unchangeable, we know that all iron sulphide is formed in the same manner.

If any other proportions of iron and sulphur are taken, some of either the iron or the sulphur will be left over in its native state, as it can not enter into the new body except in the proportions named. This is called a Chemical Combination, and this same principle underlies the formation of all minerals.

What is Mineralogy?

4. MINERALOGY is the science which treats of Minerals, and as usually presented, includes the study of their composition, physical properties and chemical characteristics, but the latter properly belongs to Chemistry, so nothing but a few basic principles of Chemistry will be considered here.

More than one thousand minerals have been discovered and classified by mineralogists, but 90 per cent. of these are of scant interest to the mining man. Twenty minerals of first importance make up nine-tenths of the earth's crust. Only those minerals that occur in quantities to make them of commercial importance, or those that are associated with mineral deposits will have extended consideration under this subject.

What are Elements?

5. Nearly all minerals are *compounds*,—that is, they are composed of two or more substances, which makes a knowledge of each component part necessary in order to satisfactorily determine the identity of a mineral and classify it.

The Ancients divided all matter into four classes, Earth, Air, Fire, Water, and called these elements. Science, however, does not recognize these as Elements at all. Water and Air are made up of gases. Fire results from the union of several elements, while the Earth itself comprises all the elements.

AN ELEMENT is defined to be a substance that can not be divided or separated into simpler substances by any known process; in a word it is one of the *primary* forms of matter.

At the present time there are about eighty recognized simple substances called Elements. Several of these have been discovered within the last half century and we have good reason to believe that some substances now classed as elements may be shown in the future to be compounds of two or more simpler substances. A full discussion of Elements belongs to Chemistry, but inasmuch as the study of Minerals involves some knowledge of Elements this subject must have brief attention here.

NATIVE ELEMENTS are those that are found at times free in nature. There are fifteen of these, the remaining sixty-three elements have never been found except in combination with one or more elements.

What are Compounds?

6. A COMPOUND is made up of two or more simple elements. While a few elements occur *free*, these same

elements are found in greater abundance combined with other elements and are then called Compounds.

What are Symbols and Formulas?

7. A SYMBOL is a short method of expressing an element,—in other words, an abbreviation. Many elements are expressed by the first letter in the name, as O, the symbol of Oxygen. When several elements have the same initial another letter in the name is added to distinguish it, as Os, the symbol for the element Osmium. Most symbols are abbreviations of the English words, but the metals known to the Ancients have symbols derived mainly from the Latin or Greek. Fe is the symbol for Iron, from the Latin *Ferrum*. The symbol for Gold is Au, from the Latin *Aurum*.

A FORMULA is a combination of symbols, and as applied to a mineral, expresses in a brief way all the elements that enter into the compound. For example: Quartz is a compound, made up of two elements Silicon and Oxygen, Si is the symbol for Silicon, and O is the symbol for Oxygen, combined we have (SiO_2) the formula for Quartz.

This formula conveys to us the information that Quartz is composed of one volume of Silicon and one volume of Oxygen, the number 2 below the O, signifies that the Oxygen volume consists of two parts or atoms.

Mineralogists have arranged formulas for nearly all mineral compounds, which show at a glance all the elements in the compound, and with a knowledge of their combining weight of each the proportions or percentage of each element can be calculated.

How are Elements Classified?

8. Since the Eighteenth Century, it has been customary to divide elements into two classes (1) Metals and (2) Metalloids. The ending *oid* means like or resembling, and Metalloids are so named because they resemble metals in some of their properties. In fact the resemblance is sometimes so close that it is hard to draw a line to distinguish the two classes. If metalloids possessed a metallic appearance, they might be classed as metals. Combinations of metalloids form acids.

Modern Classification of Elements

Later authorities now divide elements into three classes, viz:

- (1) Metals.
- (2) Semi-Metals.
- (3) Non-Metals.

The following table, consisting of forty-eight elements, includes about all that are of particular interest to the mining man. The rarer elements, of which there are about thirty additional, are outside the purview of this book and hence do not merit consideration here.

COMMON MINERAL ELEMENTS

NAME	SYMBOL	NAME	SYMBOL
Aluminum	Al	†Molybdenum	Mo
† <i>Antimony</i> (L. Stibium)	Sb	Nickel	Ni
† <i>Arsenic</i>	As	* <i>Nitrogen</i>	N
Barium	Ba	Osmium	Os
†Bismuth	Bi	* <i>Oxygen</i>	O
<i>Boron</i>	B	Palladium	Pd
‡ <i>Bromine</i>	Br	<i>Phosphorus</i>	P
Cadmium	Cd	Platinum	Pt
Calcium	Ca	Potassium (Kalium)	K
<i>Carbon</i>	C	<i>Selenium</i>	Se
* <i>Chlorine</i>	Cl	<i>Silicon</i>	Si
Chromium	Cr	Silver (Argentum)	Ag
Cobalt	Co	Sodium (Natrium)	Na
Copper (L. Cuprium)	Cu	Strontium	Sr
* <i>Fluorine</i>	Fl	<i>Sulphur</i>	S
Gold (L. Aurum)	Au	†Tantalum	Ta
* <i>Hydrogen</i>	H	† <i>Tellurium</i>	Te
<i>Iodine</i>	I	Tin (L. Stannum)	Sn
Iridium	Ir	†Titanium	Ti
Iron (L. Ferrum)	Fe	†Tungsten (Wolfram)	W
Lead (L. Plumbum)	Pb	Uranium	Ur
Magnesium	Mg	†Vanadium	V
Manganese	Mn	†Zinc	Zn
‡Mercury (Hydrargyrum)	Hg	Zirconium	Zr

The names printed in Italics are classed as Metalloids.

*Signifies Gaseous element.

†Sometimes classed as Semi-Metals.

‡Liquid at ordinary temperatures.

How are Minerals Grouped?

8. Minerals are grouped according to the principal element in their composition as follows:

- | | |
|-----------------|----------------|
| (a) Oxides | (j) Carbonates |
| (b) Sulphides | (k) Silicates |
| (c) Arsenides | (l) Nitrates |
| (d) Antimonides | (m) Borates |
| (e) Tellurides | (n) Phosphates |
| (f) Chlorides | (o) Molybdates |
| (g) Iodides | (p) Vanadates |
| (h) Bromides | (q) Tungstates |
| (i) Fluorides | |

What Do the Endings Signify?

9. The older authorities used the endings, *ide*, *ate* and *ite*, in various ways, but they are now used generally to signify certain groups of minerals. The ending *ide* is used to denote the union of *two* elements in a compound. the ending *ate* denotes a union of *three or more* elements in a compound.

The ending *ite* was used for *ide* as in Sulphide, but now seldom used in this way. *Ite* is a common ending of many minerals, especially those that are named after their discoverers, like Jamesonite, etc.

Oxides

10. OXYGEN (O) is a gaseous element, so abundant that it constitutes about one-fifth of the atmosphere, eight-ninths of water by weight and nearly half of the Earth's solid crust. Oxygen forms compounds with all other elements except Fluorine and enters into the composition of most all minerals in the Oxide Zone.

The union of Oxygen with another element produces Oxides, which form an important group of minerals. When

certain elements as sulphur (S), Carbon (C), Phosphorus (P), and Iron (Fe), are brought into contact with Oxygen at suitable temperatures, they burn evolving heat and produce oxides of these substances. Oxygen is intensely active and unites with other elements in different proportions owing to the conditions present. The principal group of minerals thus formed are called Oxides; the sub-groups of minerals ending in *ate* are called Oxygen Salts.

PRINCIPAL OXIDE MINERALS

MINERAL	FORMULA	NAME
<i>Water</i>	(H ₂ O)	Hydrogen Oxide.
<i>Quartz</i>	(Si O ₂)	Silicon Oxide.
<i>Cuprite</i>	(Cu ₂ O)	Copper Oxide.
<i>Zincite</i>	(Zn O)	Zinc Oxide.
<i>Lime</i>	(Ca O)	Calcium Oxide.
<i>Corundrum</i>	(Al ₂ O ₃)	Aluminum Oxide
<i>Hematite</i>	(Fe ₂ O ₃)	Iron Oxide.
<i>Minium</i>	(Pb O)	Lead Oxide.
<i>Manganosite</i>	(MnO)	Manganese Oxide.
<i>Arsenolite</i>	(As ₂ O ₃)	Arsenic Oxide.
<i>Bismite</i>	(Bi ₂ O ₃)	Bismuth Oxide.
<i>Valentinite</i>	(Sb ₂ O ₃)	Antimony Oxide
<i>Tellurite</i>	(Te ₂ O ₃)	Tellurium Oxide.
<i>Tungstite</i>	(W O ₃)	Tungsten Oxide.
<i>Cassiterite</i>	(Sn O ₂)	Tin Oxide.
<i>Rutile</i>	(Ti O ₂)	Titanium Oxide.
<i>Periclase</i>	(Mg O)	Magnesium Oxide.

Sulphides

11. SULPHUR is an element found native in volcanic districts. When sulphur enters into a combination with another element it produces what are called Sulphides. Sulphur combined with two or more elements produces Sulphates.

Nearly all Minerals found below the natural water level are Sulphides, hence the name Sulphide Zone.

PRINCIPAL SULPHIDE MINERALS

MINERAL	FORMULA	NAME
Argentite	(Ag ₂ S)	Silver Sulphide.
Galena	(Pb S)	Lead Sulphide.
Chalcocite	(Cu ₂ S)	Copper Sulphide.
Sphalerite	(Zn S)	Zinc Sulphide.
Cinnabar	(Hg S)	Mercury Sulphide.
Millerite	(Ni S)	Nickel Sulphide.
Marcasite	(Fe S ₂)	Iron Sulphide.
Realgar	(As S)	Arsenic Sulphide.
Stibnite	(Sb ₂ S ₃)	Antimony Sulphide.
Bismuthinite	(Bi ₂ S ₃)	Bismuth Sulphide.
Molybdenite	(Mo S)	Molybdenum Sulphide
Patronite	(V S ₄)	Vanadium Sulphide.

SULPHATE MINERALS

Barite	(Ba SO ₄)	Barium Sulphate.
Celestite	(Sr SO ₄)	Strontium Sulphate
Anglesite	(Pb SO ₄)	Lead Sulphate.
Gypsum	(Ca SO ₄)	Calcium Sulphate.
Epsomite	(Mg SO ₄)	Magnesium Sulphate.
Alunogen	(Al ₂ SO ₄)	Aluminum Sulphate.

Arsenides

12. ARSENIC (As) is an element often found native in primitive rocks, which fact often puzzles the miner and prospector. This element enters into compounds forming *Arsenide Minerals*.

- Niccolite* (Ni As) Nickel Arsenide.
- Smaltite* (Co As₂) Cobalt Arsenide.
- Domeykite* (Cu₃As) Copper Arsenide.
- Sperrylite* (Pt As₂) Platinum Arsenide.

Compounds of Arsenic, Sulphur and other elements are sometimes classed as Sulph-arsenites.

Antimonides

13. ANTIMONY (Sb) occurs native and is then known as Gray Antimony. It enters into combination with a number of elements forming *Antimonides*.

PRINCIPAL ANTIMONIDE MINERALS

Stibnite (Sb_2S_3) Antimonide of Sulphur.
Dyscrasite (Ag_3Sb) Antimonide of Silver.
Horsfordite (Cu Sb) Antimonide of Copper.
Breithauptite (Ni Sb) Antimonide of Nickel.

Antimony forms compounds with Sulphur and other elements, which are classed as Sulph-Antimonates. Compounds of Antimony with oxygen and another element are called Antimonates, also Antimonites.

Tellurides

14. Tellurium (Te) is an element that is never found native, but forms compounds with other elements known as *Tellurides*. This element has no present value in itself, but is associated with very rich metal ores.

PRINCIPAL TELLURIDE MINERALS

Sylvanite (Au Te, Ag) Gold and Silver Telluride.
Krennerite (Au Te) Gold Telluride.
Hessite (Ag Te) Silver Telluride.
Tetradamite (Bi Te) Bismuth Telluride.
Coloradoite (Hg Te) Mercury Telluride.
Altaite (Pb Te) Lead Telluride.
Melonite (Ni Te) Nickel Telluride.
Nagyagite (Au Pb Sb Te S) Telluride.

Chlorides

15. Chlorine (C) is a gaseous element never found free, but always combined with other elements and forms Chlorides. It is a solvent for gold.

PRINCIPAL CHLORIDE MINERALS

- Halite* (Na Cl) Sodium Chloride.
Calomel (Hg Cl) Mercuric Chloride.
Cerargyrite (Ag Cl) Silver Chloride.
Atacamite (Cu Cl) Copper Chloride.
Sylvite (K Cl) Potassium Chloride.
Sal Ammoniac (N H Cl) Ammonium Chloride.

Iodides

16. *Iodine* (I) is a solid element which combines to form a few minerals, called *Iodides*. The following are the principal minerals:—

- Iodyrite* (Ag I) Iodide of Silver.
Marshite (Cu I) Copper Iodide.

Bromides

16. *Bromine* (Br) is a liquid element which combines with Chlorine and Iodine to form a few compounds, viz:

- Bromyrite* (Ag Br) Bromide of Silver.
Embolite (Ag, Cl, Br) Silver Chloro-Bromide.

Fluorides

17. *Fluorine* (Fl) is a gaseous element that unites with other elements to form a few minerals as follows:—

- Fluorite* (Ca Fl) Calcium Fluoride.
Cryolite (Na Al Fl) Fluoride of Sodium and Aluminum.
Sellaite (Mg Fl) Magnesium Fluoride.

Carbonates

18. The element Carbon (C) is found native crystallized in the Diamond and in a modified form in Graphite. Charcoal and Coal are common forms of Carbon. Carbon unites with Oxygen and metallic elements to form an important group of minerals known as *Carbonates*.

PRINCIPAL CARBONATE MINERALS

- Calcite* (CaCO_3) Calcium Carbonate.
Siderite (FeCO_3) Iron Carbonate.
Smithsonite (ZnCO_3) Zinc Carbonate.
Strontianite (SrCO_3) Strontium Carbonate.
Azurite (CuCO_3) Copper Carbonate.
Rhodochrosite (MnCO_3) Magnesium Carbonate.
Witherite (BaCO_3) Barium Carbonate.
Cerussite (PbCO_3) Lead Carbonate.
Natron (Na_2CO_3) Sodium Carbonate.
Bismutite (BiCO_3) Bismuth Carbonate.

Silicates

19. The element Silicon (Si) is never free, but always combined with Oxygen. Quartz, the Oxide of Silicon, is commonly called silica, and when three elements enter into the combination, *Silicates* are formed. Next to Oxygen, Silicon is the most plentiful of all elements and is the principal constituent of all rocks except coal and limestone.

PRINCIPAL SILICATE MINERALS

- Cryscolla* (CuSiO_3) Copper Silicate.
Garnierite (NiMgSi , Etc.) Nickel Silicate.
Kaolinite (AlSiO_3) Aluminum Silicate.
Talc (MgSiO_3) Magnesia Silicate.
Calamine (ZnSiO , Etc.) Zinc Silicate.
Actinolite (CaMgFeSiO) Calcium and Magnesium Silicate.
Orthoclase (K, AlSiO) Potash Silicate.
Albite (Na, Si, Al, O , Etc.) Sodium Silicate.

Nitrates

20. NITROGEN (N) is a very abundant element, constituting four-fifths of the atmosphere by bulk, combined with Oxygen. When alone, Nitrogen is inactive, but the few com-

pounds into which it enters are the most energetic known. The principal Nitrates are as follows:

- Soda Niter* (Na NO_3) Sodium Nitrate.
- Niter* (Saltpeter KNO_3) Potash Nitrate.
- Gerhardite* (Cu NO_3 etc.) Copper Nitrate.
- Nitrobarite* (Ba NO_3 etc.) Barium Nitrate.

Borates

21. The element Boron (B) is found in nature in the form of a salt known as Borax (Na, B O). Two other compound minerals are important, viz:—

- Colmanite* (Ca B O , etc.) Borate of Lime.
- Boracite* (B, Mg, O, Cl , etc.) Magnesium Borate.

Phosphates

22. PHOSPHORUS (P) is never found free in nature, but forms compounds with a few elements and the minerals which are known as *Phosphates*:—

- Apatite* (P, Ca, Cl, O , etc.) Calcium Phosphate.
- Pyromorphite* (P, Cl, O, Pb) Lead Phosphate.

NOTE: Phosphate of Lime is the result of animal accumulations of bones, etc.; deposits of Guano are valuable as fertilizers. The Phosphate minerals named no doubt receive their Phosphorus content from dissolved animal matter.

Tungstates

23. The element *Tungsten* (Wolfram, W) is never found free, but always in combination with a few elements forming *Tungstates*, as follows:—

- Wolframite* (W, Fe Mn O) Iron Tungstate.
- Scheelite* (W, Ca O) Calcium Tungstate.
- Hubnerite* (W, Mn O) Manganese Tungstate.
- Stolzite* (W, Pb O) Lead Tungstate.

Molybdates

24. MOLYBDENUM (Mo) is an element that is found only in a few compounds known as Molybdates, as follows:

Wulfenite (Mo Pb O) Lead Molybdate.

Powelite (Mo Ca O) Calcium Molybdate.

NOTE: The chief ores of Molybdenum are *Wulfenite* and *Molybdenite* (Mo S₂) ; the latter is grouped under Sulphides (Par. 11).

Vanadates

25. VANADIUM (V) is a rare element and combines with only a few elements to form Vanadates. This element is usually associated with Lead.

Vanadinite (V Pb Cl O) Lead Vanadate.

Descloizite (V Pb) Lead Vanadate.

NOTE: Vanadium occurs in the mineral *Roscoelite* (V Mn Si Fe, etc.) as a Silicate.

What Are Known as Alikali Minerals?

26. The elements Sodium, Potassium, Calcium, Barium and Magnesium are the principal Alkali Minerals. They are generally soluble in water, giving it a soapy taste and feel. Alkali restores the blue color to vegetable blues (*Litmus*) that have turned red from acids, in other words alkalies neutralize acids. The Alkali minerals are mainly Chlorides, Carbonates, Nitrates and Sulphates, and have been mentioned under those groups. Alkali minerals are metallic or basic.

What Are the Acid Minerals?

27. AN ACID is the exact opposite of an alkali, and has the property of changing Vegetable blues (*Litmus*) to red tints. Quartz is the most common acid mineral. Com-

pounds of Arsenic, Antimony, Bismuth, Sulphur, Tellurium, Boron, Molybdenum, Tungsten and Vanadium are usually classed Acid Minerals.

PHYSICAL PROPERTIES OF MINERALS

28. The Physical properties of minerals are those that we may observe by the Physical Senses,—Touch, Taste, Smell and Sight. In examining a mineral these senses convey certain impressions to the mind, which makes certain inferences or draws conclusions more or less imperfect, according to one's knowledge and skill, which can only be acquired by practice.

(a) *TOUCH*, or Feel, is the sense that enables one to determine if a substance is harsh, gritty, smooth or greasy, as in Silica, Graphite, Talc, etc.

(b) *TASTE*. This is important only in a few minerals that are soluble in water. Examples: Halite is *Saline* (salty); Natron is *alkaline* and Carnalite is *bitter*.

(c) *SMELL*. (Odor.) Most minerals are odorless under ordinary conditions, but when struck with a sharp instrument or heated, a few give off characteristic odors. Example: Arsenopyrite (Mispickel) is said to be *Allicious*, that is gives off an odor of Garlic; Pyrite emits Sulphurous fumes; Asphaltum has Bituminous odor, etc.

(d) *SIGHT* is the most important of the senses as it is by this that Color, Luster, Fracture, Cleavage, Crystalliza-

tion, etc., are made possible of determination. The distinctive characteristics of minerals are:

- (1) *Luster.*
- (2) *Color and Streak.*
- (3) *Hardness.*
- (4) *Gravity.*
- (5) *Fracture.*
- (6) *Cleavage.*
- (7) *Tenacity.*
- (8) *Crystal System.*

The importance of these properties varies in different minerals. For example, Gravity may distinguish one mineral more clearly than all the other physical properties; another mineral's color alone may be so characteristic as to identify it, but there are some mineral compounds that nothing short of a chemical analysis will disclose their identity. However, most all the common minerals may be determined off-hand by these physical properties.

(1) Luster

29. The *Luster* of a mineral is due to the reflection of light on its surface. There are several degrees of luster as follows:—

(a) *Metallic* is the luster of metal, but if the resemblance to metal is only slight, it is said to be Sub-metallic.

(b) *Vitreous* is the term used to denote glassy luster.

(c) When it has the luster of rosin it is said to be *Resinous*.

(d) *Greasy* when it looks like smeared with oil.

(e) *Pearly*, when the luster of a pearl.

(f) *Silky*, when like silk.

(g) *Adamantine* is the luster of the Diamond.

(h) *Earthy* or dull is the term used when there is no luster at all.

(2) Color

30. The Color of a mineral often affords a good means of identification. Some minerals when powdered give a *Streak* (color) different from the color of the specimen as a whole. The streak color may be obtained by drawing a projecting point of the mineral specimen across a piece of unglazed porcelain, or a streak plate, but the characteristic streak color is best obtained by pulverizing the mineral and rubbing the powdered pulp with the tip of finger on a white unglazed paper. The following are the characteristic colors of the principal minerals:

DISTINCTIVE MINERAL COLORS

RED

Rose-Red Rose Quartz
Orange-Red Wulfenite
Purplish-Red Cinnabar
Brick-Red Jasper
Blood-red Zincite

GREEN

Olive-Green Olivine
Sage-Green Serpentine
Sea-Green Fluorite
Apple-Green Garnierite
Grass-Green Malachite

VIOLET

Reddish-Violet Amethyst
Bluish-Violet Sodalite

GRAY

Smoke-Gray Limestone
Bluish-Gray Anhydrite

YELLOW

Orange-Yellow Orpiment
Ochre-Yellow Ochre
Resin-Yellow Opal
Honey-Yellow Calcite
Brownish-Yellow, Dolomite

BLUE

Indigo-Blue Covellite
Sky-Blue Cyanite
Greenish-Blue Chrysocolla
Azure-Blue Lazurite

BROWN

Clove-Brown Limonite
Yellowish-Brown Wood Opal.

WHITE

Snow-white Magnesite
Reddish-white Barite
Greenish-white Talc

METALLIC COLORS

Lead-Gray ...	Molybdenite	Silver-white ..	Arsenopyrite
Bronze-Yellow ..	Pyrrhotite	Brass -Yellow .	Chalcopyrite

(3) Hardness

31. THE HARDNESS of a mineral is that property which enables it to scratch or be scratched, but does not have reference to the breaking of a mineral itself. Hardness is determined by comparison with other minerals used as a standard. The following scale is used by all mineralogists:

SCALE OF HARDNESS

(1) TALC. The softest mineral easily scratched with finger nail.

(2) GYPSUM. The finger nail scratches with difficulty. A copper coin scratches Gypsum, but it will not scratch copper.

(3) CALCITE. Can not be scratched with finger nail. It will scratch pure copper as well as Gypsum.

(4) FLUORITE. Can not be scratched with copper coin. An ordinary pin will not scratch it. The point of a knife will scratch Fluorine easily.

(5) APATITE. Will scratch Fluorite or Calcite, Scratches glass with difficulty. Is easily scratched by knife.

(6) FELDSPAR (Orthoclase or Serpentine). Will scratch glass; can be scratched with point of knife with difficulty.

(7) QUARTZ. Can not be scratched with knife; yields with difficulty to a file; scratches glass easily.

(8) TOPAZ. Scratches quartz and most other minerals.

(9) CORUNDRUM. Nothing but a Diamond will scratch Corundrum and all other minerals yield to it.

(10) DIAMOND. The hardest known mineral; scratches all minerals.

Any mineral in this scale will scratch all in the scale below it, but will scratch no mineral above it. Quartz or flint is common everywhere, and may be used as a standard; anything that can be scratched with a sharp corner of quartz is below 7 in the scale of hardness.

IN PRACTICAL FIELD TESTS, the finger nail, a copper coin, the point of a knife and a piece of flint will enable one to determine the hardness of most any mineral, likely to be found.

TABLE OF HARDNESS OF COMMON MINERALS

No. 1 to 1.5

Minerals that can be scratched with finger nail:—

Nagyagite	Sternbergerite	Cerargyrite
Embolite	Lead	Calomel
Nitratine	Molybdenite	Arsenolite
Elaterite	Ozocerite	Talc

No. 2 to 2.5

Minerals that scratch with finger nail with great difficulty, but are easily scratched with a copper coin:—

Sylvanite	Calaverite	Krennerite
Argentite	Pyrargyrite	Proustite
Stephenite	Bromyrite	Galena
Jamesonite	Minium	Vanadinite
Cinnabar	Pyrolusite	Tobernite
Brucite	Gypsum	Sylvite
Borax	Niter	Tellurium
Orpiment	Realgar	Bismuth
Tetradymite	Graphite	Gilsonite
Bituminous Coal	Muscovite	Kaolinite

No. 3 to 3.5

Minerals that will scratch Copper and Gypsum, viz:—

Stromeyerite	Antimony	Barite
Domeykite	Hessite	Chalcocite
Cuprite	Tetrahedrite	Altacamite
Crysocolla	Olivenite	Anglesite
Pyromorphite	Altaite	Sphalerite
Millerite	Cerussite	Coloradoite
Magnesite	Genthite	Calcite
Aragonite	Dolomite	Arsenic (native)

No. 4 to 4.5

Minerals a pin will not scratch but the point of a knife scratches easily:—

Azurite	Wolfenite	Zincite
Calamine	Iron	Pyrrhotite
Siderite	Rhodochrosite	Stannite
Scheelite	Fluorite	Colmanite

No. 5 to 5.5

Minerals that will scratch Calcite and Fluorite, but scratch glass with great difficulty:—

Dioptase	Smaltite	Cobaltite
Niccolite	Arsenopyrite	Hematite
Willemite	Magnetite	Chromite
Limonite	Manganosite	Uranite
Hubernite	Wolframite	Apatite
Pyroxene	Amphibole	Hornblende
Titanite	Natrolite	Smithsonite

No. 6 to 6.5

Minerals that will scratch glass and can be scratched with point of knife only with difficulty:

Franklinite	Pyrite	Vessuvianite
Rutile	Turquoise	Sodalite
Garnet	Epidote	Chrysolite
Andesite	Albite	Orthoclase
Cyanite	Marcasite	Cassiterite
Opal	Serpentine	Zolsite

No. 7 to 7.5

Minerals that scratch glass easily and do not yield to knife:—

Quartz	Amethyst	Agate
Flint	Jasper	Zircon
Hyacinth	Tourmaline	Iolite

No. 8 to 8.5

Minerals that will scratch quartz and most all other minerals:—

Beryl	Topaz	Spinel
Chrysoberyl	Almandine (Ruby)	Disluite

No. 9

Corundrum	Sapphire	Oriental Ruby
Oriental Topaz	Oriental Emerald	Oriental Amethyst

(4) Specific Gravity

32. This property is next in importance to Hardness. It refers to the weight of a substance using water as a standard of comparison, which is taken as the unit or 1; if the Specific Gravity of a mineral is given as 2 then we understand it is twice as heavy as the same volume of water. If gravity is 3, then the mineral is three times the weight of water, and so on.

The rule to determine Specific Gravity is to weigh the substance in air, then weigh it in water. Divide the weight in air by the loss of weight in water, and the quotient is the Specific Gravity. A simple method of determining Gravity is to attach the mineral to a silk thread, which will enable it to be weighed in air and water. For example, if a piece of mineral weighs 4 oz. in air, and 3 oz. suspended in water, the difference is 1 oz.; this divided into 4, the weight in air, gives the Specific Gravity as 4.

A PRACTICAL FIELD METHOD where weighing is out of the question and for an approximate determination, take a piece of quartz or granite, the Gravity of which is 2.5 to 2.8. Nearly all the metal minerals are heavier than quartz. If a specimen of equal size appears twice as heavy as quartz, you can safely conclude that its Gravity is 5 or better. If weight is about half more then gravity would be 4 or less. An accurate determination of Gravity is seldom required in the study of minerals.

The following is the approximate Specific Gravity of minerals that may be used as standards of comparison, viz:

SPECIFIC GRAVITY

Anthracite	1.6	Sphalerite	4.0	Wolframite	7.1
Opal	2.1	Malachite	4.0	Galena	7.5
Gypsum	2.3	Witherite	4.3	Argentite	7.8
Quartz	2.7	Pyrite	5.0	Cinnabar	8.0
Cryolite	3.0	Arsenopyrite	6.0	Sylvanite	8.3
Apatite	3.2	Smaltite	6.2	Uraninite	9.2
Limonite	3.8	Cassiterite	6.7	Sperrylite	10.6

(5) Fracture

33. The term *Fracture* is used to describe the kind of surface left exposed from breaking a mineral, not along the regular cleavage plane. There are three kinds of fracture in minerals as follows:—

(a) *Conchoidal* (Conc—A Shell). When a fractured mineral leaves curved shell-like surfaces, it is said to be *Conchoidal*. Example: Quartz.

(b) *Even* is the term used to denote more or less regular fracture, which is rare. Lithograph Stone has Even Fracture.

(c) *Uneven* is the word used to describe rough Fractures as in Chalcocite, Calamine and Pyrite.

(6) Cleavage

34. Most minerals when struck, break where the cohesive force is weakest, along certain planes and this property is called Cleavage. This property differs in minerals owing to the character of crystals in the mineral. (See Crystal Systems.)

(7) Tenacity

35. TENACITY is that property in a substance that causes the particles to cling together. There is quite a difference in the tenacity of minerals, but in any one substance the property is pretty uniform. The different degrees of Tenacity are classified as follows:—

(a) BRITTLE. This is a term used to show condition when a mineral breaks easily or the parts separate into powder when cut with a knife.

(b) MALLEABLE. When mineral can be cut into slices and can be beaten flat under a hammer without flying to pieces, it is said to be Malleable, as copper.

(c) SECTILE. When very thin slices may be cut off with a knife as in all malleable minerals, it is said to be Sectile, as Embolite.

(d) FLEXIBLE. When a substance can be bent and remain so, it is said to be flexible. Most all malleable minerals have this property.

(e) ELASTIC. When a substance returns to its original form after being bent it is said to be Elastic like Muscovite, or Mica.

(8) Crystalline Structure

36. Minerals present a variety in structure owing to the more or less imperfect crystallization. The naked eye

alone is often unable to detect any crystals in a mineral, but the structure is nevertheless crystalline, probably composed of minute grains.

There are a number of terms used by mineralogists to denote different structures, which it will be well to explain.

(1) COLUMNAR. Structure is said to be Columnar when made up of slender columns. The varieties of Columnar structure are as follows:—

(a) *Fibrous*. When columns are parallel fibers as in Asbestos.

(b) *Reticulated*. A net-like appearance of fiber.

(c) *Stellated*. Fibers radiating like star points.

(d) *Radiated*. When fibers spread out fan-like as in Stibnite.

(2) LAMELLAR. When structure is in plates or leaves like Mica.

(3) GRANULAR. When composed of fine grain crystals. If grains are too small to be distinguished with the naked eye, structure is said to be *impalpable*.

(4) IMITATIVE. There are several terms used to describe a structure which imitates objects, viz:—

(a) Reniform—Kidney-shaped.

(b) Botryoidal—Grape-like.

(c) Mamillary—Breast-shaped.

(d) Dendritic—Tree-shaped.

(e) Capillary—Hair-like.

(f) Acicular—Needle-shaped.

(g) Stalactitic—like Stalactites in caves.

Crystal Form

37. When matter changes from a liquid to a solid state it tends to form into crystals. A common example is water

freezing to form ice and snowflakes, the latter of which assumes an infinite variety of Crystals.

All minerals have at some time been in the liquid state, and it is believed that originally they were gases. Whether the liquid from which mineral crystals were formed results from dissolved matter (solution) or from fusion (melting), scientists are not fully agreed, but the fact that crystals are formed in the laboratory from both solutions and fusions, makes it reasonably certain that these are nature's processes within the earth. We know that gases condense to liquids and that liquids in cooling form solids, and in solidifying minerals form bodies with geometric forms, having faces and angles, and these bodies are called crystals.

In some instances these crystals are so characteristic that a mineral may be identified and classified by crystals alone. But the geologic forces acting on the crystallizing bodies compress and distort them so that crystals are drawn out of shape often rendering expert knowledge and unusual skill necessary to determine a crystal definitely.

Then crystals vary in size in the same mineral. For example, quartz occurs in minute crystals as well as of a size weighing tons. How then may they be distinguished? No matter what size crystals assume there is always a uniformity of character in the angles and faces, that is, each edge of a crystal face, as well as the angles formed where two lines meet, always bear the same relation to each other, whether large or small. The measurement of crystals and angles is a delicate operation, impossible to any one except an expert, so does not merit consideration here.

Crystallography

38. That branch of Mineralogy which treats of crystal forms is called Crystallography. The variety of crystal forms is almost endless; for example, the mineral Cuprite occurs in well defined cubes and also in needle shaped crystals, which are simply cubes elongated or drawn out but still retaining their characteristic angles and faces.

Notwithstanding the variety in crystals they have all been reduced and classified under six forms, viz:—

- (1) *Isometric.*
- (2) *Tetragonal.*
- (3) *Hexagonal.*
- (4) *Orthorhombic.*
- (5) *Monoclinic.*
- (6) *Triclinic.*

(1) ISOMETRIC (Equal measure). The crystals of this system are called Isometric, because the axes or lines enclosing a crystal face are of equal length, and in their primary forms the surfaces are exactly alike.

The *Cube* is the basal form of this system and the normal type is found in Galena, Magnetite and Fluorite, and in somewhat modified forms in the minerals Cuprite and Garnet. Gold crystals also belong to the Isometric system. (See Fig. 32.) A slightly modified form of the Isometric is found in the mineral Pyrite shown in Fig. 33. The faces are bounded by lines called axes, which are of equal length and the angles are all likewise equal.

(2) TETRAGONAL. (Four Angles.) The elementary forms of this system are the square (four-sided) and the octagon (eight-sided) prisms, with pyramids at each end. The mineral Zircon is a true type of the Tetragonal system

and is shown in Figs. 34 and 35. The unit prism is m , and p is the unit pyramid. Two edges of the prisms are of equal length, the third is usually either longer or shorter. The unequal axis is called the vertical and the equal axes are called the lateral. Pyrite, Stolzite and Rutile belong to the Tetragonal system.

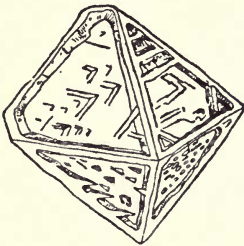


Fig. 32. Gold Crystal.
Isometric

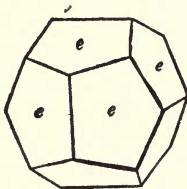


Fig. 33. Pyrite.
Isometric

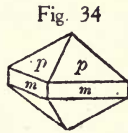


Fig. 34



Fig. 35
Zircon
Tetragonal

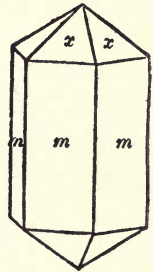


Fig. 36. Apatite

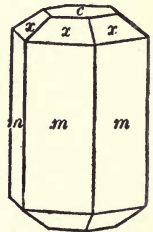


Fig. 37. Apatite
Hexagonal

(3) HEXAGONAL. (Six Angles.) This system of crystals closely resembles the Tetragonal except that the faces occur in multiples of three, that is 6, 9, 12, etc., while the Tetragonal crystal faces occur only in multiples of two, as 4, 6, 8, etc. The elementary crystal forms in each are the prism and pyramid. The mineral Apatite (Figs. 36 and 37) is a representative type of this system; the unit prism is m ,

forming a six-sided solid. The unit pyramid is x , which has three axes, the vertical being at right angles with the lateral axes. The minerals Beryl and Iodyrite also belong to this system, and represent the normal types.

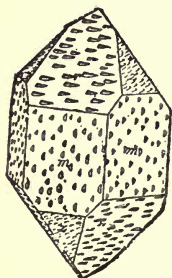


Fig. 41. Quartz
Rhombohedral



Fig. 40. Quartz
Rhombohedral

Fig. 38. Calcite

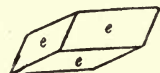


Fig. 39. Calcite
Rhombohedral

There is a subdivision of the Hexagonal system that deserves notice, viz:—

(a) RHOMBOHEDRAL. The word is derived from *Rhomb* (revolve) and *Hedral* (base). The crystal faces of the Rhombohedral are parallelograms, that is, they have four unequal sides and angles, and there are three exposed crystal surfaces. The mineral *Calcite* is the natural type of this sub-group as shown in Figs. 38 and 39. *Siderite*, *Hematite* and *Corundrum* are Rhombohedral. Another type is shown in Figs. 40 and 41, Quartz. The unit prism is m , and the Rhombohedron is r , a pyramid. The minerals Dolomite, Willemite, and Cinnabar have crystals of the Quartz type.

(4) ORTHORHOMBIC. (Straight-rhomb-like). In this system the three axes of a crystal face are equal, but form right angles with each other. The mineral Sulphur is a common type of the Orthorhombic as shown in Fig. 42.

The pyramid is p , and the base c . Cerussite, Chrysolite and Calamine are all modified forms of the Orthorhombic system.

(5) MONOCLINIC. (One incline.) The crystals of this system have rectangular bases with only one incline of the three unequal axes. *Gypsum* is the normal type of the Monoclinic system shown in Figs. 43 and 44. The unit prism is m , and b is the base.

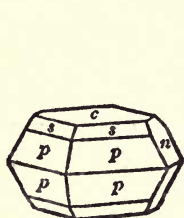


Fig. 42. Sulphur
Orthorhombic



Fig. 43.
Gypsum
Monoclinic

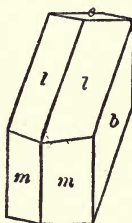


Fig. 44. Gypsum
Monoclinic

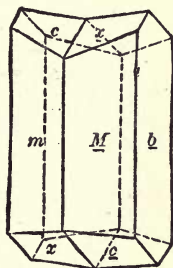


Fig. 45. Albite
Triclinic

The minerals belonging to this system are numerous, but the following are the most common, viz: Orthoclase, Augite, Hornblende, Cryolite, Muscovite, Azurite, Borax and Colmanite.

6. TRICLINIC. (Three inclines). The axes of the Triclinic system are all unequal and incline towards one another, hence the name. This system does not include many minerals. The normal type is the mineral Abite (Soda Feldspar) shown in Fig. 45. The unit prism is m , and the base is c ; the connecting angles are all inclined. Labradorite and Cyanite are representative types of this system.

What Causes the Endless Variety of Crystals?

39. The six Systems named include all known forms of crystals, but perfect crystals are not common and irregularities are so frequent as often to require an expert to determine their identity. This irregularity is due to the fact that when the crystal was forming, being in a plastic or wax-like condition, temperature and pressure conditions prevented it assuming its normal shape. Crystals, for this reason may be flattened, drawn out, curved and twisted. Compound minerals, being made up of different elements that in a state of purity would tend to form normal crystals, result in an irregular crystalline structure.

What Are Pseudomorphs?

40. The word Pseudomorph means *false* form, and as applied to minerals has a similar significance to Metamorphs in rocks. The processes of crystal change, resulting in Pseudomorphs are known as:—

- (1) *Substitution.*
- (2) *Deposition.*
- (3) *Alteration.*

(1) SUBSTITUTION. This is illustrated in a lime rock giving up its calcareous matter and the element Silicon entering the cavities formed to replace the dissolved lime.

(2) DEPOSITION. Quartz crystals sometimes form on the mineral Fluorite by the deposit of a silicious solution and the mineral Anglesite forms on Cerussite by incrustation.

(3) ALTERATION. This is the most common change in minerals, and the most active agents are the gases. Thus Azurite giving up its oxygen, water and carbonic acid, forms native copper, by loss of some of its constituents. The min-

eral Brochantite, giving up its sulphur and water forms Cuprite,—a copper oxide, which in turn taking up carbonic acid is changed to Malachite, a copper carbonate. Pyrite giving up its sulphur and taking on oxygen forms the mineral Limonite.

Internal Imperfections and Inclusions

41. A mineral in crystallizing sometimes includes an air bubble, a liquid globule or organic matter like Bitumen, etc., so that it results in an imperfectly crystallized mineral, and these things result in that infinite variety which perplex the mineralogists and often render chemical analysis necessary to correctly classify a mineral.

Other Simple Mineral Tests

42. The physical properties already explained do not involve any physical or chemical change in the composition or structure of a mineral. There are two simple tests on minerals that involve changes both physical and chemical which may with propriety be considered under the subject Mineralogy, as follows:

FUSIBILITY

When a mineral can be melted simply by the application of heat it is said to be *fusible*; however, if Fluxes (Chemical Reagents) are necessary to fuse a mineral, it is said to be infusible. In order to determine the fusibility of a mineral, and the ease or difficulty with which this may be accomplished, mineralogists have adopted a scale, beginning with unity 1, representing the most fusible mineral, and advancing

to 6, the most difficultly fusible mineral. Anything above 6 in the scale is said to be *infusible*. The following is the scale and the typical minerals used by way of comparison, viz:—

FUSIBILITY SCALE

(1) STIBNITE (Antimony). Most fusible mineral known; melts in large pieces in ordinary candle flame. A lighted match will fuse small splinters of Stibnite.

(2) NATROLITE (Natron Soda). Fusible in candle flame in small splinters, but more difficult than Stibnite.

(3) RED GARNET (Almondite). Fusible in Blow Pipe flame, but withstands candle flame even in the smallest splinters.

(4) ACTINOLITE. Easily fusible in Blowpipe flame in small pieces, but large pieces fuse only with difficulty.

(5) ORTHOCLASE (Feldspar). Fusible in Blowpipe flame in small pieces, large pieces will not melt.

(6) BRONZITE (Serpentine). Almost infusible in Blow-pipe flame. Very fine splinters are slightly rounded on edges, but require a lens to detect any change.

(7) QUARTZ. Infusible in Blow Pipe flame even on the thinnest edges.

In the examination of a mineral specimen as to fusibility, it is tested in candle flame and if found infusible by this method then the Fusibility is above 2, and Blow Pipe must be used. A splinter of the mineral to be tested should be held in a forceps, ground to a thin point, so as not to conduct away too much heat.

TABLE OF FUSIBILITY OF COMMON MINERALS

No. 1		
Sylvanite	Calavarite	Hessite
Livingstonite	Proustite	Stephenite
Cerargyrite	Embolite	Jamesonite
Zinkenite	Mendipite	Grunauite
Cinnabar	Coloradoite	Epsomite
Orpiment	Realgar	Krennerite
No. 1½		
Petzite	Nagyagite	Sylvite
Pyrargyrite	Tetrahedrite	Valentinite
Vanadinite	Cerussite	Argentite
Halite	Borax	Tetradimite
No. 2		
Chalcopyrite	Galena	Wulfenite
Niccolite	Breithauptite	Arsenopyrite
No. 2½		
Chalcocite	Smaltite	Anglesite
Olivenite	Covelite	Bornite
No. 3		
Atacamite	Cuprite	Stolzite
Malachite	Azurite	Wolframite
Cobaltite	Pyrrhotite	Gypsum
Boracite	Fluorite	Atacamite
Witherite	Melaconite	
No. 4		
Barite	Celestite	Pyroxine
Amphibole	Hornblende	Labradorite
Andesite	Titanite	Hubnerite
No. 5		
Sphalerite	Smithsonite	Willemite
Calamine	Leucopyrite	Siderite
Apatite	Beryl	Muscovite
Biotite	Talc	Scheelite

No. 6

Diopase	Genthite	Limonite
Franklinite	Chromite	Rutile
Magnetite	Cassiterite	Topaz
Pyrolusite	Corundrum	Alunogen
Uranite	Spinel	Crysocolla
Amethyst	Magnesite	Hematite
Turquoise	Zincite	Gummite

INFUSIBLES

Rhodochrosite, Diamond, Quartz, Asbestos, Cyanite, Topaz, Agate, Jasper, Opal.

Acid Mineral Tests

43. A simple test to determine a carbonate mineral is to drop a little acid on the mineral ; if it is a carbonate, it will cause an effervescence (fizzing) due to the carbonic acid set free. Limestone effervesces most freely. A more satisfactory test for one of the common mineral carbonates is to pulverize the mineral and place the pulp in a glass or porcelain vessel and then apply the acid. In the absence of Nitric, Hydrochloric or Sulphuric acids, a good quality of vinegar, which is a diluted fruit acid, will give fair results.

Particles of free gold in a mineral may be tested by dropping a little acid on it; if the metallic particles remain unchanged in luster, etc., then you may be reasonably certain it is gold. Pyrites are only slightly affected by acids, but a change in luster is always noticeable which serves to distinguish them from gold.

CHEMICAL PROPERTIES OF MINERALS

44. The determination of a pure mineral by its physical properties is not difficult, but complex minerals require careful and persistent examination to make an accurate determination of their identity. The final and conclusive test on a mineralogical specimen is a chemical analysis, which subject is outside the purview of this book.

It must, however, be borne in mind that the chief distinction between a mineral and a rock is in their chemical composition. *A rock is an aggregate of minerals, a mere mixture, while a mineral has a definite and fixed proportion of elements in its composition.* If the identity of a certain mineral is established by physical properties heretofore named, a chemical determination or assay is unnecessary, because the composition of every pure mineral is known and its percentage of elements shown in mineralogical tables. For example: If we test a mineral and find it has all the properties of say Chalcocite, turn to the mineralogical table for that mineral and you will find it is composed of 79.8% copper and 20.2% sulphur and never otherwise if pure. In ordinary practice perfect minerals are rare, owing to impurities present. Suppose the mineral is only 50% pure, then there would be approximately 40% copper and so on.

In Mineralogical tables the composition is usually given, either in the way of a formula or expressed in percentage, calculated from the the formula, in other words you have the *answer* at the beginning, whereas in actual practice this would come at the end of the examination.

How to Examine and Determine Minerals

45. In the usual study of minerals, specimens of the normal types which have been determined by an expert, as

to their physical and chemical properties are used for the reason that a *real* object is more interesting than a picture or word description. Every one engaged in the study of minerals should have at least specimens of such minerals at hand that he is most interested in.

Such a collection may be obtained from dealers in minerals at reasonable rates and will be found of great assistance as the characteristics may be learned much as we learn to know a person by his distinctive physical features. Then a determined mineral may be tested by each of the physical properties, as Hardness, Gravity, etc., which tends to fix these in the mind better than is possible in any other way. It is, however, possible to form an acquaintance with the more common minerals from a description alone, and this plan will have consideration at this time.

The minerals hereafter described are those usually found in cabinets of High Schools and Schools of Mines, each being a normal type of the group to which it belongs, and should be of particular interest to all students of mining. The physical properties are given in the order previously named.

DESCRIPTIVE MINERALOGY

Gold (Au) Minerals

46. Gold is a metallic element, which with one exception is always in a free or native state. Gold is widely distributed and occurs in a variety of rocks, and in sea water, though in such relatively small quantities as to be of little importance. It enters into, and is associated with all classes of mineral compounds, but usually in a state of mixture only, the fine gold flakes and dust are coated with sulphur, arsenic, iron, etc., so that the gold is invisible even with a

magnifying glass. Such mineral compounds are said to be refractory although the Gold content is thought to be actually free.

In the early days of mining, Gold was thought to exist only in quartz (except in placers) and this mineral is its natural home. Iron and quartz have a strong affinity for Gold, so sections of quartz veins that contain the most iron are generally the richest.

The only recognized chemical combination of Gold with another element is in the Tellurides, where gold and Tellurium are in a real chemical composition, with fixed proportion for each.

Gold Telluride Minerals

47. SYLVANITE. Composition, Au 28.5%, Te 55.8%, Ag 15.7%. Luster, metallic; Color, steel-gray, silver white to brass-yellow; Hardness, 1.5 to 2; Streak, gray; Cleavage, uneven; Tenacity, sectile; Crystals, triclinic, resembling Hebrew written characters, hence sometimes called *Graphic Tellurium*. Fusibility 1.

CALAVARITE. Composition, Au 44.5%, Te 55.5%. Luster, metallic; Color and Streak, gray to bronze-yellow; Hardness, 2.5; Gravity, 9.4; Fracture, uneven; Tenacity, sectile; Crystals, triclinic; Fusibility, 1.

NAGYAGITE. Composition, Au, Pb, Sb, Te, S, somewhat variable. Luster, metallic; Color and Streak, blackish-gray; Hardness, 1 to 1.5; Tenacity, foliated; Crystals, orthorhombic; Fusibility, 1.5.

PETZITE. Composition, Au 25.6%, Ag 41.85%, Te, 32.68%. Luster, metallic; Color, iron-gray; Streak, grayish; Hardness, 2.5 to 3; Gravity, 8 to 9; Frac-

ture, uneven; Tenacity, sectile to brittle; Crystals, massive; Fusibility, 1.5.

KRENNERITE. Composition, Au, Te. Luster, metallic; Color, silver-white to brass-yellow; Streak, gray; Hardness, 2.5; Gravity, 8.35; Cleavage, basal; Crystals, orthorhombic; Fusibility, 1.

Remarks: The Telluride minerals are among the heaviest known and this alone will serve to identify them. When Tellurium appears in an ore it indicates increased metal values.

Silver (Ag) Minerals

48. *Silver* is found native in bulk and also in crystal form. It enters into combinations with a variety of elements to form valuable minerals. Silver is also found in a state of alloy with gold in ores varying from 5 to 35% silver. Silver occurring in quartz with gold is usually free-milling. Silver minerals that contain lead and copper sulphides are called *Smelting Ores*. Those containing antimony, arsenic, sulphur and zinc are termed *Refractory Ores*. The Silver minerals constitute a large group, so only the more common are described below, viz:

Silver Glance

ARGENTITE (Silver Glance). Composition, Ag 87.1%, S 12.9%. Luster, metallic; Color and Streak, blackish to lead-gray; Hardness, 2 to 2.5; Gravity, 7.6; Fracture, conchoidal; Tenacity, very sectile; Crystals, isometric; Fusibility, 1.5.

STROMEYERITE. Composition, Ag 53.1%; Cu 31.2%, S 15.7%. Luster, metallic; Color and Streak, dark-gray; Hardness, 2.5 to 3; Gravity, 6.25;

Fracture, uneven; Tenacity, sectile; Crystals, orthorhombic; Fusibility, 1.5.

HESSITE. Composition, Ag 62.8%, Te 37.2%. Luster, metallic; Color and Streak, grayish; Hardness, 2.5 to 3; Gravity, 8.4; Fracture, uneven; Tenacity, sectile; Crystals, isometric; Fusibility, 1.

PYRARGYRITE (Ruby Silver). Composition, Ag 59.8, Sb 22.5%, S 17.7%. Luster, metallic to adamantine; Color and Streak, black to dark-red; Hardness, 1.5 to 2; Gravity, 5.8; Fracture, conchoidal; Crystals, hexagonal; Cleavage, imperfect; Fusibility, 1.

PROUSTITE (Light Ruby Silver). Composition, Ag 65.5%, As 15.1%, S 16.2%; Sb. Luster, splendant to adamantine; Color, light ruby-red; Streak, scarlet-red; Hardness, 2 to 2.5; Gravity, 5.5; Fracture, conchoidal; Tenacity, sectile to brittle; Crystals, hexagonal; Fusibility, 1.

STEPHENITE (Brittle Silver). Composition, Ag 68.5%, As 15.1%, S 16.2%, (Sb). Luster, sub-metallic; Color and Streak, iron-black; Hardness, 2 to 2.5; Gravity, 6.25; Fracture, uneven; Tenacity, sectile to brittle; Crystals, orthorhombic; Fusibility, 1.

POLYBASITE. Composition, Ag 64%, As, Cu. Luster, metallic; Color and Streak, black; Hardness, 2 to 2.5; Gravity, 6.2; Fracture, uneven; Tenacity, sectile to brittle; Crystals, monoclinic; Fusibility, 1.

CERARGYRITE (Horn Silver). Composition, Ag 75%, Cl 24.6%. Luster, resinous to wax-like; Color, green, gray to blue; Streak, shining; Hardness, 1.5 to 2; Gravity, 5.4; Fracture, uneven, compact; Tenacity,

malleable; Crystals, rare, isometric in small cubes; Fusibility, 1.

Remarks: When this mineral occurs massive it appears horn-like, hence its name, which does not refer to its appearance in the "horn-spoon," as some think.

IODYRITE. Composition, Ag 46%, 1.54%. Luster, resinous to waxy; Color and Streak, yellow; Fracture, uneven; Cleavage, basal; Gravity, 5.6; Tenacity, sectile to malleable; Crystals, hexagonal; Fusibility, 1.

EMBOLITE. Composition, Ag, Cl, Br. Luster, resinous; Color, olive-green to yellowish; Streak, shining; Hardness, 1 to 1.5; Gravity, 5.5; Crystals, isometric; Fusibility, 1.

BROMYRITE. Composition, Ag 57.4%, Br 42.6%. Luster, adamantine; Color, greenish, bluish to yellow; Streak, yellowish-green; Hardness, 2 to 3; Gravity, 5.9; Fracture, uneven; Tenacity, malleable; Crystals, isometric; Fusibility, 1.

Copper (Cu) Minerals

49. **COPPER (Cu)** is an element that frequently occurs free as a result of nature's processes. It crystallizes in the isometric system in more or less distorted cubes. It also occurs native in the shape of fine grains, most noticeably in the region of Lake Superior. Copper combines freely with various elements to form compounds which minerals are the chief source of the commercial metal. The Copper minerals of most importance are the following:

CUPRITE (Ruby Copper Ore). Composition, Cu 88.8%, O, 21.1%. Luster, adamantine to earthy; Color and Streak, deep-red to brownish-red; Hardness, 3.5; Grav-

ity, 6 to 6.5; Fracture, uneven, compact; Tenacity, brittle; Crystals, isometric in ideal cubes; Fusibility, 2.5 to 3.

MELACONITE (Black Copper Ore). Composition, Cu 78.9%, O, 21%. Luster, sub-metallic; Color and Streak, grayish-black; Hardness, 3 to 4; Gravity, 6; Fracture, uneven; Tenacity, brittle to earthy; Crystals, monoclinic; Fusibility, 3.

Remarks: Ores of Melaconite frequently contain earthy impurities such as sulphur, iron, arsenic and manganese.

CHALCOPYRITE (Copper Pyrites). Composition, Cu 34.6%, Fe 30.5%, S 34.9%. Luster, shining; Color, brass-yellow to deep yellow; Streak, greenish-black; Hardness, 3.5 to 4; Gravity, 4.3; Fracture, uneven; Tenacity, sectile to brittle; Crystals, tetragonal; Fusibility, 2.

Remarks: This mineral occurs in various rocks, frequently associated with galena and with other copper ores.

CHALCOCITE (Copper Glance). Composition, Cu 79.8%, S 20.2%. Luster, shining; metallic; Color and Streak, blackish-lead-gray; Hardness, 2.5 to 3; Gravity, 5.5; Fracture, uneven; Tenacity, knife cuts it; Crystals, orthorhombic; Fusibility, 2 to 2.5.

Remarks: Chalcocite closely resembles Argentite (silver Sulphide) but is not sectile.

BORNITE (Peacock Copper). Composition, Cu 55.5%, Fe 16.3%, S 28.6%. Luster, metallic; Color, blue to copper red; Streak, grayish-black; Fracture, uneven; Hardness, 3; Gravity, 4.5 to 5; Tenacity, sectile to brittle; Crystals, isometric; Fusibility, 2.5.

Remarks: Bornite is distinguished from Chalcopyrite by its bronze-red to copper-red color on fresh fractured surfaces.

TETRAHEDRITE (Gray Copper). Composition, Cu 25.5%, S, As, Ag, Hg. Luster, metallic; Color, steel-gray to blackish-gray; Streak, brown to cherry-red; Hardness, 3 to 4.5; Gravity, 4.7 to 5.6; Fracture, uneven; Tenacity, brittle; Crystals, isometric; small but perfect; Fusibility, 1.5 to 2.

MALACHITE (Green Copper Carbonate). Composition, Cu 71.9%, C 19.9%, O. Luster, adamantine to vitreous; Color, light-green; Streak, pale-green; Hardness, 3.5 to 4; Gravity, 3.7 to 4; Fracture, uneven to fibrous; Tenacity, brittle; Crystals, monoclinic; Fusibility, 3.

Remarks: This mineral is a common outcrop of copper veins and when hard and solid takes a fine polish as an ornamental stone.

AZURITE (Blue Copper Carbonate). Composition, Cu 69.2%, C 25.6%, O. Luster, vitreous to transparent; Color deep azure-blue; Streak, bluish; Hardness, 3.5 to 4.5; Gravity, 3.5 to 3.8; Fracture, conchoidal or uneven; Tenacity, brittle; Crystals, monoclinic; Fusibility, 3.

Remarks: Azurite occurs with Malachite at copper outcrop, giving a stain to associated rocks.

CHRYSOCOLLA (Copper Silicate). Composition, Cu 45.3%, Si 34.2%. Luster, shining to earthy; Color, clear bluish-green; Hardness, 2 to 4; Gravity, 2 to 2.5; Fracture, uneven; Tenacity, sectile to brittle; Crystals, massive, never crystallized; Fusibility, 6.

Remarks: Chrysocolla occurs in thin seams in crevices as an incrustation.

ATACAMITE (Copper Chloride). Composition, Cu 58.7%
Cl 32.8%. Luster, adamantine to vitreous;
Hardness, 3 to 3.5; Fracture, conchoidal; Tenacity, brittle;
Crystals, orthorhombic; Fusibility, 3 to 4.

OLIVENITE (Copper Arsenide). Composition, Cu 56.15%,
As 40.6. Luster, vitreous to adamantine;
Color and Streak, olive-green to brown; Hardness, 3;
Gravity, 4.25; Fracture, uneven; Tenacity, brittle-fibrous;
Crystals, orthorhombic, ideal, symmetry; Fusibility, 2 to 2.5.

Lead (Pb) Minerals

50. **LEAD (Pb)** is a very common element, never occurs native, but its compounds are quite numerous. The lead minerals are all heavy and quite soft and these properties alone give a clue to the class to which they belong. The following are the principal Lead minerals:

GALENA (Lead Glance). Composition, Pb 86.6%, S
13.4%. Luster, metallic, shining; Color and
Streak, lead-gray; Hardness, 2.5; Gravity, 7.25; Fracture,
granular; Cleavage, cubic; Crystals, isometric, ideal cubes;
Fusibility, 2.

Remarks: Galena occurs in granite, limestone and sandstone and is often associated with copper and zinc ores. The ore matrix is quartz, calcite, and fluor-spar. Galena is the most common as well as the most important lead ore. All Galena ores carry some silver, ranging from 1 to 10%.

CERUSITE (White Lead Ore). Composition, Pb 83.5%
C 16.5%. Luster,, adamantine; Color and
Streak, white to grayish; Hardness, 3 to 3.5; Gravity, 6.5;

Fracture, conchoidal; Tenacity, brittle; Crystals, orthorhombic; Fusibility, 1.5.

Remarks: Cerusite is a valuable lead carbonate ore and runs to Galena with depth.

JAMESONITE (Feather Ore). Composition, Pb, Sb, S. Luster, sub-metallic; Color, blackish lead-gray; Streak, black; Hardness, 2 to 3; Gravity, 5 to 5.5; Fracture, uneven; Tenacity, brittle; Crystals, orthorhombic; Fusibility, 1.

ANGLESITE. Composition, Pb 64.1%, O, 24%, S 14.8%. Luster, adamantine to resinous; Color, white-gray to green; Streak, white to gray; Hardness, 2.5 to 3; Gravity, 6.4; Fracture, conchoidal; Tenacity, brittle; Crystals, orthorhombic; Fusibility, 2.5.

Remarks: Anglesite is an important Lead ore and occurs in the Oxide Zone, running to Galena with depth.

PYROMORPHITE. Composition, Pb, As, O, Cl. Luster, resinous, sub-transparent; Color, green, brown, yellow to gray; Streak, white; Hardness, 3.5 to 4; Gravity, 7; Fracture, uneven; Tenacity, brittle; Crystals, hexagonal prisms; Fusibility, 2.

Remarks: Occurs in veins with other lead ores.

MIMETITE. Composition, Pb, As, O, Cl. Luster, resinous to adamantine; Color, pale brownish-yellow; Streak, white to gray; Hardness, 2.5 to 3.5; Gravity, 6.4; Fracture, uneven; Tenacity, brittle; Crystals, hexagonal; Fusibility, 1.5.

Zinc (Zn) Minerals

61. **ZINC (Zn)** is an element said to occur native only in Australia, and this is somewhat doubtful. The

compounds of Zinc are quite numerous; when it occurs in the ores of other metals it makes them refractory and subject to penalties at the smelters according to the Zinc content. Zinc is the most difficultly fusible of all metallic ores. The following are the principal Zinc minerals:—

SPHALERITE (Zinc Blende). Composition, Zn 67%, S 33%. Luster, resinous to waxy; sub-metallic; Colors, various, from brownish-yellow, black, green, red and white; Streak, white to reddish-brown; Fracture, conchoidal; Tenacity, brittle; Hardness, 3.5 to 4; Gravity, 4; Crystals, isometric modified cubes; Fusibility, 5.

Remarks: Sphalerite is called “Black-jack” by the miners. It is the most common and valuable Zinc ore of commerce and occurs frequently in sulphide copper and lead ores. Zinc ores carry gold and silver at times but in too small proportions to be extracted with profit except as a by-product in Zinc smelting.

SMITHSONITE (Zinc Carbonate). Composition, Zn 52%, C 9.76%, O 38.24%. Luster, vitreous or pearly; Color, whitish-green to brown; Streak, uncolored; Hardness, 5; Gravity, 4.4; Fracture, uneven; Tenacity, brittle; Fusibility, 5; Crystals, rhombohedral.

Remarks: The massive mineral is called “dry-bone” by miners from its characteristic appearance. Smithsonite is an important Zinc ore, nearly always associated with silicates.

CALAMITE (Zinc Silicate). Composition, Zn 67.5, Si 25%. Luster, vitreous to pearly; Color, whitish, bluish-green to brown; Streak, white; Hardness, 4.5 to

5; Gravity, 3.25; Fracture, uneven; Tenacity, brittle; Crystals, orthorhombic; Fusibility, 5.

Remarks: Calamine occurs associated with other Zinc ores.

ZINCITE (Red Zinc Ore). Composition, Zn 80.3%, O 19.7%. Luster, brilliant to adamantine; Color, bright red to yellow; Streak, orange-red; Hardness, 4 to 4.5; Gravity, 5.7; Fracture, mica-like; Cleavage, perfect; Tenacity, lamina, brittle; Crystals, hexagonal—well defined; Fusibility, 6.

Remarks: Zincite occurs with other Zinc ores, especially Franklinite and Willemite.

FRANKLINITE (Black Zinc Ore). Composition, Zn, Fe, Mn, etc. Luster, sub-metallic; Color, iron-black; Streak, dark reddish-brown; Hardness, 5.5 to 6.5; Gravity, 4.5 to 5; Cleavage, indistinct; Tenacity, brittle; Crystals, isometric; Fusibility, 6.

Remarks: Usually occurs in coarse grains, resembling Magnetite and is associated with Calcite, Zincite and Willemite.

WILLEMITE (Zinc Silicate). Composition, Zn, O, Si. Luster, vitreous, transparent to opaque; Color, whitish-green; Streak, uncolored; Hardness, 5.5; Gravity, 4; Fracture, uneven; Tenacity, brittle; Crystals, rhombohedral; Fusibility, 5.

Remarks: Willemite occurs with Franklinite and Zincite, so as to make it an important Zinc ore.

Cobalt (Co) Minerals

52. **COBALT** (Co) is an element never found native, but combines with Sulphur, Arsenic and Antimony to form

several compounds. Cobalt is usually associated with Nickel and has recently attracted attention on account of the Silver found associated with it in Canadian ores. It is highly magnetic like Nickel, but retains its magnetism permanently. The principal Cobalt minerals are the following:—

SMALTITE (Cobalt Arsenide). Composition, Co 25%, Ni, As. Luster, metallic; Color, tin-white to steel-gray; Streak, grayish-black; Hardness, 5.5 to 6; Gravity, 6.5; Fracture, uneven; Cleavage, cubic; Tenacity, brittle; Crystals, isometric; Fusibility, 2.5.

COBALITE (Cobalt Glance). Composition, Co 35.5%, As 45.2, S 19.3%. Luster, metallic; Color, silver-white; Streak, grayish-black; Hardness, 5.5; Gravity, 6.3; Fracture, uneven; Cleavage, cubic; Tenacity, brittle; Crystals, isometric; Fusibility, 2 to 3.

ASBOLITE (Cobalt Oxide). Composition, Co and O 24%, Mn and O 76%. Luster, dull to sub-metallic; Color, blue to blue-black; Tenacity, earthy; Crystals, massive.

Nickel (Ni) Minerals

53. **NICKEL (Ni)** is an element found in native state only in meteoric iron. It combines with other elements to form a small group of compounds. Nickel is magnetic, but loses its magnetism when heated and this fact assists in its determination. Nickel minerals are not widely distributed, but where they occur they are quite valuable. The following are the principal Nickel minerals:—

GARNIERITE (Nickel Silicate). Composition, Ni, Mg, O, Si. Luster, resinous to earthy; Color, apple-green; Streak, greenish-white; Hardness, 2.5; Gravity, 2.3.

Remarks: Garnierite is never crystallized, resembles Chrysocolla; occurs in Serpentine rocks and is of minor importance as an ore.

MILLERITE (Nickel Sulphide). Composition, Ni 64.4%, S 33.6%. Luster, metallic; Color, brass-yellow; Streak, bright; Hardness, 3 to 3.5; Gravity, 5.5; Fracture, uneven; Tenacity, brittle; Crystals, rhombohedral; Fusibility, 2.

NICCOLITE (Nickel Arsenide). Composition, Ni 44%, As, Sb. Luster, metallic; Color, copper-red; Streak, pale-brown; Fracture, uneven; Hardness, 5 to 5.5; Tenacity, brittle; Crystals, hexagonal; Fusibility, 2.

Mercury (Hg) Minerals

54. **MERCURY (Hg)** is the only element that is a liquid at ordinary temperature. It forms alloys with several metals but has the greatest affinity for silver and gold. Mercury minerals are few and not widely distributed; they occur as a rule in metamorphic rock. The Mercury minerals are very heavy, and this permits working ores running as low as 2% by concentration process. The following are the principal Mercury minerals:—

CINNABAR (Mercury Sulphide). Composition, Hg 86%, S 14%. Luster, dull to adamantine; Color, bright-red to brown; Streak, scarlet-red; Hardness, 2 to 2.5; Gravity, 8 to 9; Tenacity, sectile-pulverizes; Crystals, hexagonal; Fusibility, 1; volatilizes at about 1.5.

COLORADOITE (Telluride of Mercury). Composition, Hg, Te. Luster, metallic; Color and Streak, grayish to black; Hardness, 3; Gravity, 8.6; Fracture, uneven; Crystals, rare-massive; Fusibility, 1; Volatile at 1.5 to 2.

Tin (Sn) Minerals

55. **TIN (Sn)** occurs native in placers and is then called "Stream Tin." It forms a few compounds with other elements, which are quite valuable, but of limited occurrence. The two principal Tin minerals are:—

STANNITE (Tin Sulphide). Composition, Sn 27%, Cu, Fe, S. Luster, metallic; Color, steel-gray to iron-black; Streak, blackish; Fracture, uneven; Tenacity, brittle; Hardness, 4; Gravity, 4.5; Crystals, tetragonal; Fusibility, 5 to 6.

Remarks: Stannite is also called "Tin Pyrites."

CASSITERITE (Tin Oxide). Composition, Sn 78%, O 22%. Luster, adamantine; Color, black, brown to yellow; Streak, pale-gray to brown; Hardness, 6 to 7; Gravity, 6.4 to 7; Fracture, uneven, granular; Tenacity, brittle; Crystals, tetragonal; Fusibility, 5 to 6.

Remarks: This mineral is called "Tinstone" by the miners and is the chief source of the world's supply of the metal.

Tungsten (W) Minerals

56. **TUNGSTEN (W.** from Wolfram) is never free and as an element forms only a few compounds, which are valuable and now much sought after owing to its great value in steel manufacture. This element was unknown until within the last century. The following are the principal Tungsten minerals, viz:—

WOLFRAMITE (Tungstate of Iron). Composition, W 51.25%, Mn 15%, Fe 16%, O 18%. Luster, shining to dull; Color, dark grayish-black; Streak, reddish-brown; Hardness, 5 to 5.5; Gravity, 7 to 7.5;

Fracture, uneven; Tenacity, brittle; Crystals, monoclinic; Fusibility, 3 to 3.5.

HUBNERITE (Tungstate of Manganese). Composition, W 61%, Mn 18%, O 21%. Luster, resinous; Color, brown to black; Streak, grayish-brown; Hardness, 5 to 5.5; Gravity, 6; Fracture, uneven; Tenacity, brittle; Crystals, monoclinic; Fusibility, 7.

SCHEELITE (Tungstate of Calcium). Composition, W 61%, Ca 14%, O 22%. Luster, vitreous; Color, white, yellow-brown, green; Streak, white to gray; Hardness, 4.5 to 5; Gravity, 6; Tenacity, brittle; Crystals, tetragonal; Fusibility, 5.

Remarks: Scheelite occurs in California, Wolframite and Hubnerite in Colorado, Arizona and Nevada. Tungsten ores to be marketable should contain 40 to 50% Tungsten and be free from sulphur and phosphorus. The high specific gravity of these minerals makes concentration easy so that a 60% concentrate can be produced from ores containing 5 to 10% Tungsten.

Titanium (Ti) Minerals

57. This is a rare element of recent discovery. It forms a few compounds of importance. Titanium (Ti) is used in the manufacture of artificial teeth, coloring porcelain and in certain alloys of iron and steel.

The principal Titanium minerals are as follows:

RUTILE (Titanium Oxide). Composition, Ti 61%, O 39%. Luster, metallic; Color, red to black; Streak, light-brown; Hardness, 6 to 6.5; Gravity, 4.25; Fracture, uneven; Tenacity, brittle; Crystals, tetragonal; Fusibility, 5 to 6.

Remarks: This is the principal commercial mineral.

TITANITE (Silicate of Titanium). Composition, Ti, O 40.83%, Si 30.6%, Ca 23%. Luster, adamantine to resinous; Color, grayish-brown to black; Streak, uncolored; Fracture, uneven; Cleavage, prismatic; Tenacity, brittle; Crystals, monoclinic; Hardness, 5 to 5.5; Gravity, 3.5; Fusibility, 4.

Vanadium (V) Minerals

58. **VANADIUM (V)** is a rare element of recent discovery; it forms a few compounds with other elements of value. Vanadium is used in the manufacture of steel, giving it uniformity of structure, prevents crystallization, and increases the tensile strength of steel when 0.1% or less is used in an alloy. The following are the principal Vanadium minerals:—

VANADINITE. Composition, V, Pb, O, Cl. Luster, resinous to greasy; Color, yellow, red to brown; Streak, light-yellow; Hardness, 2.5 to 3; Gravity, 7; Fracture, uneven; Tenacity, brittle; Crystals, hexagonal; Fusibility, 1.5.

Remarks: Vanadate is sometimes classed a Lead mineral. Vanadium is also associated with the element Uranium.

Uranium (U) Minerals

59. **URANIUM (U)** is an element that has been known to mineralogists for some years but has recently excited interest from the fact that Radium (Ra), a very rare element and almost priceless in value, has been extracted from Uranium minerals. The principal are the following:—

URANINITE (Pitch Blende). Composition, U 81.5%, O 13.47%, Pb 3.97%. Luster, sub-metallic or dull; Color, grayish, brownish to velvet-black; Hardness, 5.5; Gravity, 6.4 to 9.3; Fracture, uneven; Tenacity, brittle; Crystals, isometric; Fusibility, 6.

CARNOTITE. Composition, U, V, K, O, etc. Color, bright canary-red; Scale-like; Crystals, microscopic. Highly radio-active.

Molybdenum (Mo) Minerals

60. **MOLYBDENUM (Mo)** is a somewhat rare element. and forms few compounds. It is one of the steel hardening elements which is growing in importance. It imparts to steel properties similar to Tungsten. The process of treatment to recover Molybdenum from an ore is expensive, hence only high grade minerals are of importance. The following are the principal Molybdenum minerals:—

MOLYBDENITE (Molybdenum Sulphide). Composition, Mo 59%, S 41%; Color and Streak, lead-gray; Luster, metallic; Hardness, 1 to 1.5; Gravity, 4.5; Cleavage, foliated like Graphite; Tenacity, sectile; Crystals, hexagonal; Fusibility, 6.

WULFENITE (Lead Molybdate). Composition, Mo 35%, Pb 65%. Luster, vitreous to resinous; Color, yellow to grayish; Streak, gray; Hardness, 5; Gravity, 6; Fracture, uneven; Tenacity, brittle; Crystals, orthorhombic; Fusibility, 2.

Remarks: Wulfenite is sometimes classed as a Lead Mineral.

Bismuth (Bi) Minerals

61. **BISMUTH (Bi)** is sometimes found native and is classed as a semi-metal. It is used largely as an alloy on

account of its low melting point. Bismuth forms a few compounds with other elements. These minerals are often associated with gold and silver and it is always an indicator of increased richness in an ore. The following are the most important Bismuth minerals:..

BISMUTHINITE (Bismuth Glance). Composition, Bi 81%, S 19%. Color and Streak, lead-gray; Hardness, 2; Gravity, 6.4; Crystals, orthorhombic.

BISMUTITE (Bismuth Carbonate). Composition, Bi 79%, O 15%, C 2%. Color, white-greenish to yellowish; Streak, greenish-gray; Hardness, 4; Gravity, 6.8; Crystals, amorphous; Tenacity, earthy.

TETRADIMITE (Bismuth Telluride). Composition, Bi 51%, Te 49%. Color, steel-gray; Streak, gray; Hardness, 1.5 to 2; Gravity, 7.6; Cleavage, basal; Tenacity, sectile, soils paper; Crystals, hexagonal; Fusibility, 1.5.

Platinum (Pt) Minerals

62. **PLATINUM (Pt)** is an element that is nearly always found native, and is associated with Gold in placers. Four other rare metals, Osmium, Palladium, Ruthenium and Rhodium are frequently associated with platinum in a state of alloy. All these metals have a high value owing to increasing demand and diminishing supply. Present price of Platinum is almost double pure gold. Most all the Platinum of commerce is obtained from placers, where it occurs with the black sands somewhat tarnished in color, but owing to its great weight, and its being insoluble in acids, enables any one to distinguish it from ordinary black sand.

Platinum ore has recently been discovered in paying quantities in Nevada; however, in the form of a mixed mineral.

Platinum forms compounds with only a few elements. The only minerals of importance are the following:—

SPERRYLITE. (Platinum Arsenide). Composition, Pt 56%, As 43%; Color, tin-white; Streak, black; Hardness, 6; Gravity, 10.6; Crystals, isometric.

Remarks: This mineral is generally found in basic rocks such as granite, serpentine, etc.

IRODOSMINE. Composition, Ir, Os, Ru, Pt, Rd; Hardness, 6; Color, tin-white to steel-gray; Gravity 19.3; Crystals, hexagonal, in minute prisms.

Iron (Fe) Minerals

63. **IRON (Fe)** is found native only in meteors, but its compounds are the most numerous of all metal minerals. Iron enters into the composition of all rocks, minerals and earths, etc., and its presence is shown by the characteristic colors of brown and yellow, due to oxidization or iron. Iron minerals are so abundant, and the market price of the metal so low, that only the purest iron minerals are of particular value.

Pure iron minerals of highest commercial value occur in the Azoic rocks, but some recent formations contain iron deposits of interest. Iron is magnetic and its presence in an ore can be detected ordinarily by its magnetic properties alone. The following are the Iron minerals of commercial interest:—

HEMATITE. (Oxide Iron). Composition, Fe, 70%, O 30%. Luster, splendent; Color, steel-gray to iron black; Streak, reddish to brown; Hardness, 5.5; Gravity, 4.5 to 5; Fracture, uneven, scaly to fibrous; Tenacity, brittle; Crystals, hexagonal; Fusibility, 6.

Remarks: Hematite is the most common iron ore; Titanium and Manganese are common impurities.

LIMONITE. (Brown Iron Ore). Composition, Fe 60%, O 26%. Luster, sub-metallic, dull to earthy; Color, brown to ochre-yellow; Streak, yellowish; Hardness, 5 to 5.5; Gravity, 3.5 to 4; Fracture, silky; Tenacity, brittle; Crystals, massive; Fusibility, 6.

Remarks: Brown and yellow ochre, are earthly varieties of limonite. Bog Iron Ore is Limonite in its first stages.

MAGNETITE. (Magnetic Iron Ore). Composition, Fe 72%, O 27%. Luster, metallic; Color, iron-black; Streak, black; Hardness, 5.5; Gravity, 6.5; Fracture, uneven; Tenacity, brittle; Crystals, isometric; Fusibility, 6.

SIDERITE. (Iron Carbonate). Composition, Fe 62%, C, O. Luster, pearly; Color, grayish to brown; Streak, uncolored; Hardness, 3 to 4.5; Gravity, 3.8; Crystals, hexagonal; Fusibility, 4.5 to 5.

Remarks: Siderite is also called *Spathic Iron*. It occurs in stratified rocks, gneiss, slate, etc.; it is distinguished from carbonates of lime and magnesia by its greater weight, and its becoming magnetic when heated.

PYRITE. (Iron Pyrites). Composition, Fe 46%, S 53%. Luster, metallic; Color, brass-yellow; Streak, brownish-black; Hardness, 6 to 6.5; Gravity, 5; Fracture, uneven; Tenacity, brittle; Crystals, isometric cubes; Fusibility, 2.5 to 3.

Remarks: Pyrite has little value commercially for its iron content, but its sulphur constituent is valuable for the manufacture of Sulphuric Acid. Pyrites are important to the miner on account of their frequent association with the

precious metals, especially Gold. Pyrite has been called "Fool's Gold," and the novice in mining is often puzzled by it, but its brassy color, its brittleness and its sulphur fumes when heated, serve to distinguish it from Gold.

PYRRHOTITE. (Magnetic Iron Pyrites). Composition, Fe 57%; Ni 3%, S 40%. Luster, metallic; Color, bronze-yellow to copper-red; Streak, grayish-black; Hardness, 3.5 to 4.5; Gravity, 4.5; Fracture, uneven; Tenacity, brittle; Crystals, hexagonal; Fusibility, 2.5 to 3.

Remarks: This is an important Nickel ore, although percentage is small, never to exceed 6%. Pyrrhotite is distinguished from Pyrite and Chalcopyrite by its magnetic character and the bronze color on a fresh fracture. It is only about half as hard as Pyrite and will not strike fire with steel like Pyrite. Hydrochloric acid decomposes Pyrrhotite, giving off the odor of rotten eggs.

Manganese (Mn) Minerals

64. **MANGANESE (Mn)** occurs in combination with other elements and rarely without oxygen. Manganese minerals are found in all rocks from the Cambrian to the Tertiary. Its principal use is in the iron and steel industry. A manganese ore to be marketable should be free from phosphorus and contain less than 12% Silica. Most Manganese ores carry Gold and Silver and are in demand by the Smelters for fluxing and their Gold and Silver content is recovered as a by-product. The following are the principal Manganese minerals:

PYROLUSITE. (Oxide of Manganese). Composition, Mn 63%, O 36%. Luster, non-metallic; Color and Streak, black; Hardness, 2 to 2.5; Gravity, 4.8; Frac-

ture, splintery; Tenacity, brittle; Crystals, orthorhombic; Fusibility, 6.

Remarks: Pyrolusite is the principal Manganese ore of commerce.

RHODOCHROSITE. (Manganese Carbonate). Composition, Mn 47%, C 10%, O 41%. Luster, vitreous; Color, rose-red to brown. Hardness, 3.5 to 4.5; Gravity, 3.5; Tenacity, brittle; Crystals, rhombohedral; Infusible, 65.

Aluminum (Al) Minerals

65. The element ALUMINUM (Al) never occurs native, although it is third in abundance in the earth's crust after Oxygen and Silicon. A few years ago Aluminum metal was considered as a chemical curiosity, but it is now produced by electrical processes at a moderate cost and bids fair to become as common as iron in the near future. An Aluminum mineral to be commercially profitable, should contain 40% or more Aluminum and be comparatively free from impurities. Aluminum Oxides are 9 in the scale of hardness and include many of the "Precious Stones." The Aluminum minerals from which the metal is extracted are from 2.5 to 5 in hardness. The following are the principal Aluminum metal minerals, viz:—

CRYOLITE. (Aluminum Fluoride). Composition, Al 13%, Fl 54%, Na 32%. Luster, vitreous; Color and Streak, white to gray; Hardness, 2.5; Gravity, 3; Fracture, uneven; Tenacity, brittle; Crystals, monoclinic; Fusibility, 1 to 1.5.

Remarks: Cryolite was the first mineral used for extracting the metal, the two elements, Sodium and Fluorine,

assisting as fluxes in original extraction process, but this mineral is not much used today on account of its scarcity and low percentage of Aluminum content.

BAUXITE. (Hydrous Aluminum Oxide). Composition, Al 40%, O 45%. Luster, sub-metallic; Color and Streak, white to brown; Hardness, 5 to 5.5; Gravity, 2.5 to 3.5; Crystals, orthorhombic.

Remarks: Bauxite is really a Limonite in which the iron has been replaced by Aluminum. This is the principal source of Aluminum metal in the United States.

CORUNDRUM. (Aluminum Oxide). Composition, Al 53%, O 47%. Luster, adamantine to vitreous, transparent to translucent; Color, blue, grayish, red, yellow to dark brown; Streak, white to gray; Hardness, 9; Gravity, 4.10; Fracture, uneven; Cleavage, basal; Tenacity, very tough; Crystals, hexagonal; Fusibility, 6.

Remarks: Corundrum is not a source of metal aluminum, being too rare; it is more valuable as an abrasive, for grinding and polishing. Grinding stones are manufactured from Corundrum and when mixed with iron oxide forms emery stones. Natural Emery is found in a few sections. Corundrum ranks next to the Diamond in hardness, being 9 in the scale. There are a number of Gem Stones, which are simply varieties of colored Corundrum. Their physical properties are identical with Corundrum, the only difference is in the color, as follows:—

- (a) Ruby (Red);
- (b) Topaz (Yellow);
- (c) Sapphire (Blue);
- (d) Emerald (Green);
- (e) Amethyst (Violet).

Aluminum forms other compounds, known as Gem Stones, as follows:

Spinel. Composition, Al 72%, Mg 28%; Colors, red, blue, green, yellow to black.

CHRYSOBERYL. Composition, Al 80.2%, Glucinium (Gl) 19.8%; Colors, greenish to brown.

TURQUOISE. Composition, Al 46.9%, P, O; Color, bluish-green.

Calcium (Ca) Minerals

66. CALCIUM (Ca) never occurs free, although it is one of the most abundant elements. It forms a compound with oxygen as Lime or Oxide of Calcium. Combined with oxygen and carbon it forms Carbonates as chalk, limestone and marble. Although Calcium was known to the ancients the metal had never been extracted until the electrical process came into use. Calcium, combined with oxygen and sulphur, forms *Gypsum*, known as *Calcium Sulphate*. As a silicate, Calcium occurs in a variety of rocks. The following are the principal Calcium minerals:—

CALCITE. (Calcium Carbonate). Composition, Ca 56%, C & O 44%. Luster, vitreous; fibrous to silky; Color, whitish to yellowish; Streak, white to gray; Hardness, 3; Gravity, 2.8; Tenacity, brittle; Crystals, hexagonal; Fusibility, 2.8.

ARAGONITE. (Calcium Carbonate). Composition, Ca 56%, C & O 44%. Luster, vitreous to transparent; Color and Streak, white to gray; Hardness, 3.5; Gravity, 2.9; Fracture, uneven; Tenacity, brittle; falls to pieces with heat; Crystals, orthorhombic; Fusibility, 6.

Remarks: Calcite and Aragonite are ideal minerals for the manufacture of lime, as they contain few impurities.

APATITE. (Phosphate of Calcium). Composition, Ca 53%, Cl, P, O. Luster, vitreous; Color, greenish to blue, and reddish brown; Hardness, 5; Gravity, 3.25; Fracture, uneven; Tenacity, brittle; Crystals, hexagonal; Fusibility, 6.

Remarks: Apatite or Lime Phosphate is the result of animal matter accumulations and forms a valuable fertilizer for land.

FLUORITE. (Calcium Fluoride). Composition, Ca 51%, Fl 49%. Luster, vitreous to adamantine; Color, light green, purple, reddish and blue; Streak, white to gray; Hardness, 4; Gravity, 3; Fracture, uneven; Tenacity, brittle; Crystals, isometric; Fusibility, 3.

Remarks: Fluorite is a common veinstone, in granites and metamorphic rocks and, when pure, is of much value as a flux; it is used in the manufacture of opalescent glass and in production of Hydrofluoric Acid, etc.

GYPSUM. (Calcium Sulphate). Composition, Ca 32%, S & O 46%. Luster, vitreous, or pearly; Color, white, yellow and brown; Streak, white or gray; Hardness, 1.5 to 2; Gravity, 2.3; Cleavage in three directions; Tenacity, brittle in opposite directions; Flexible; Crystals, monoclinic; Fusibility, 3 to 3.5.

DOLOMITE. (Carbonate of Calcium and Magnesium). Composition, Ca, C, O 54%, Mg C, O 45%. Luster, vitreous to pearly; Colors, various, whitish, yellowish, brownish to black; Streak, white to gray; Hardness, 3.5 to 4; Gravity, 2.8; Tenacity, brittle; Crystals, hexagonal; Fusibility, 6.

Remarks: This mineral is of small importance, being unsuitable for lime burning.

Barium (Ba) Minerals

67. **BARIUM (Ba)** is hard to separate from its compounds. Its salts are used in making fireworks for green colors; used also in chemical work. Barite was formerly used as an adulterant in white lead paints, and was found to stand weathering better than lead. There are only a few compounds, as follows:—

BARITE. (Barytes or Heavy Spar). Composition, Ba 65%, S, O 35%. Luster, vitreous to pearly; Colors, yellowish, bluish to brownish; Streak, white to gray; Hardness, 2.5 to 3.5; Gravity, 4.8; Fracture, granular; Crystals, orthorhombic; Fusibility, 4.

Remarks: Baryte deceives many miners by its weight, being nearly twice as heavy as quartz. It is frequently mistaken for Scheelite, but a comparison with the properties of Scheelite will show a distinct difference, the gravity and hardness of Scheelite being almost double that of Baryte.

WITHERITE. (Barium Carbonate). Composition, Ba 77%, C & O 23%. Luster, resinous; Color, yellowish to light gray; Streak, gray; Hardness, 3 to 4; Gravity, 4.25; Fracture, uneven; Tenacity, brittle; Crystals, orthorhombic; Fusibility, 2.5 to 3.

Sodium (Na) Minerals

68. **SODIUM (Na)** is one of the most abundant elements. It is found in immense deposits, combined with the element Chlorine, known as Chloride of Sodium, or common salt. All sea water, as well as the waters of many springs, contain large quantities of Sodium. The principal Sodium minerals are as follows:—

HALITE. (Rock Salt). Composition, Na 39%, Cl 61%. Luster, vitreous; Color and Streak, white or gray-

ish; Hardness, 2; Gravity, 2.25; Cleavage, cubic; Tenacity, brittle; Crystals, isometric.

NITRATINE. (Soda Niter or Chili Saltpeter). Composition, Na 36%, N & O 53%. Luster, earthy, crusts and scales; Color, white, yellowish to grayish; Streak, white or gray; Hardness, 1; Fracture, earthy; Tenacity, brittle; Taste, cooling; Crystals, hexagonal.

Remarks: Sodium is a constituent of many rocks, particularly in one species of the Feldspar group known as Plagioclase, sometimes called the lime-soda Feldspar. These include the minerals, Albite (Na 11.8%, Oligoclase (Na 8.8%, Andesite (Na 7.7%).

Potassium (K) Minerals

69. **POTASSIUM** (K from Kalium) occurs abundantly in nature, but always in combination with other elements. It exists in sea water, in mineral springs, in land plants, and is necessary to animal life. The most abundant source of Potassium is the class of Feldspar known as Orthoclase, the other Potassium minerals are no doubt formed from concentrated solutions of Orthoclase, which have become crystallized. The following are the principal Potassium minerals, viz:—

SYLVITE. (Potassium Chloride). Composition, K 52%, Cl 47%. Luster, vitreous; Taste, salty; Color and Streak, white to gray; Hardness, 2; Gravity, 2; Fracture, granular; perfect cubes; Tenacity, brittle; Crystals, isometric; Fusibility, 1.5.

NITER. (Potassium Nitrate or Saltpeter). Composition, K 39%, N 14%, O 47%. Luster, earthy; Hardness and Gravity, 2; Color, white; Fracture, conchoidal; Cleavage, perfect prisms; Tenacity, brittle; Crystals, orthorhombic; Fusibility, 1.

ORTHOCLASE. (Potash Feldspar). Composition, K 16%, Al 18%, Si 64%. Luster, vitreous to pearly; Color and Streak, white or grayish; Hardness, 6; Gravity, 2.5; Cleavage, basal; Crystals, monoclinic; Fusibility, 5.

MUSCOVITE. (Potash Mica). Composition, K 9.2%, Si 46%, Al 46%, Fe, Etc. Luster, vitreous to pearly; Color, white, green, yellow to brown; Hardness, 2 to 2.5; Gravity, 2.8; Cleavage, basal; Tenacity, tough and elastic.

Remarks: Muscovite is the principal Mica mineral, and its value is determined by the size of the sheets, the freedom from discoloration, and its elasticity. Its principal use is in electrical insulations, glazing, decorating; also used in the manufacture of lubricants.

Potassium in crystals is unknown in North America, but the element is found in solution, in Mono, Owen's and Searle's Lakes, in the State of California.

Magnesium (Mg) Minerals

70. **MAGNESIUM (Mg)** occurs abundantly, and is a constituent in many minerals. It has a variety of uses, which are increasing yearly. It is used in the arts for flash-light powders, and also in explosives; the Sulphate known as Epsom Salts, and the powdered Oxide have commercial value as medicines. Fireproof furnace linings, and plaster are made from it. Calcined Magnesia is used in paper manufacture to give glossy surface. Carbonic Acid is extracted from the carbonate for use in soda water, etc. The principal Magnesium minerals are as follows:—

MAGNESITE. (Magnesian Carbonite). Composition, Mg 47%, C & O 52%. Luster, silky to vitreous;

Color and Streak, white to grayish; Hardness, 3 to 4.5; Gravity, 3.3; Cleavage, rhombohedral; Tenacity, brittle; Crystals, hexagonal; Fusibility, 6.

SERPENTINE. (Magnesian Silicate). Composition, Mg 43%, Si 43%. Luster, greasy to resinous; Color, light to dark-green, etc.; Streak, white to gray; Hardness, 2.5 to 4; Gravity, 2.5; Fracture, uneven, splintery; Tenacity, lamellar, foliated; Crystals, massive; Fusibility, 5.5.

Remarks: The Asbestos minerals are found in Serpentine rocks and result from dissolved material separated out and crystallized in cavities and fissures. The following are the principal Magnesium minerals, viz:—

AMPHIBOLE. Composition, Mg, Ca, Si, Etc. Luster, vitreous; Color, white, green to black; Streak, white or gray; Hardness, 5 to 6; Gravity, 3; Fracture, uneven; Cleavage, prismatic; Tenacity, brittle; Crystals, monoclinic; Fusibility, 3 to 4.

Remarks: The minerals Tremolite and Actinolite, belong to the Amphibole group, which constitute a variety of Asbestos of an inferior grade, on account of the Calcium and other impurities, suitable only for manufacture of boards, roofings, pipe coverings and insulators. The market value of these minerals is about \$12.00 a ton.

CHRYBOTILE. Composition, Mg, Si, O. Luster, silky; Color, olive-green, white to gray; Fracture, fibrous; Cleavage, prismatic; Tenacity, sectile, long silky fibers, tough; Infusible.

Remarks: Chrysotile is the true mineralogical Asbestos, contains no lime, and this will usually distinguish it from

other varieties, which effervesce slightly in acids. This mineral crystallizes in fibers, which are capable of being woven into cloth, which is acid and fire-proof. The pure mineral is worth about \$100.00 a ton and the pure fiber with the silica removed is worth \$400.00 per ton. Supply of this mineral is obtained chiefly from Canada.

TALC. (Soapstone or Steatite). Composition, Mg 33%, Si 62%. Luster, pearly, feel greasy; Colors, white, green in various shades; Streak, white to gray; Hardness, 1 to 1.5; Gravity, 2.5; Fracture, earthy; Cleavage, basal; Tenacity, foliated, compact; Crystals, orthorhombic; Fusibility, 6.

Remarks: Talc has a commercial value when pure and in quantity with cheap transportation to market. American Talc sells from \$12.00 to \$20.00 a ton; French Talc, \$35.00 a ton; Italian Talc, \$45.00 a ton. Talc is used for fire-proof paints, coverings, foundry facings, electric insulators; also used in manufacture of dynamite; in glazing for wall-papers in toilet powders, and in dressing leather.

Carbon (C) Minerals

71. **CARBON (C)** occurs in its native purity, crystallized in the Diamond, and in a modified form in the mineral Graphite. The group of minerals known as Carbonates have already been described (Par. 18). Carbon is a constituent in all organic matter, both animal and vegetable. Few elements are capable of assuming so many combinations as Carbon and, for this reason, it has been called the "Enigma of Science." Wood, charcoal and coke are familiar examples of Amorphous (without form) carbon, while Coal and Petroleum are simply impure forms of Carbon.

DIAMOND. Composition, C 100%. Luster, adamantine;

Color, white, yellowish, red, blue, green and brown; Hardness, 10; Gravity, 3.5; Tenacity, brittle; Crystals, isometric; Infusible.

Remarks: Diamond is classed as infusible, that is, it can not be fused or melted, but it will burn at extremely high temperatures like any other carbon minerals.

GRAPHITE. (Plumbago or Black Lead). Composition, C 95 to 99%; Color, iron-black to dark steel-gray; Fracture, compact; Cleavage, basal; Tenacity, foliated, massive, laminae are flexible; Crystals, hexagonal; Fusibility, 6.

Remarks: Graphite is used in the manufacture of lead pencils. It is a commercial mineral and has a market value of from \$50.00 to \$100.00 per ton, according to quality.

The amorphous variety of Graphite is of little value. The foliated variety is valuable and much sought after.

(A) HYDROCARBON MINERALS

The Hydrocarbons are compounds of Carbon, Oxygen and Hydrogen, and include mineral oils as well as carbons. The following are the principal Hydrocarbons:—

ELATERITE (Elastic Bitumen). Composition, C 85%, H 15%. Color, brownish - black to jet - black; Hardness, 2; Gravity, 1.25.

Remarks: Elaterite is very elastic, having the appearance of india rubber; it is malleable and burns readily with a yellow flame. *Ozocerite* is similar in physical characteristics and composition. These minerals are thought to be Petroleum robbed of its volatile matter and are chiefly paraffine with some Naptha and Benzine. *Ozocerite* is used in making wax candles, etc.

ASPHALTUM (Wurtzelite). Composition, C, H, O; Color, black; Hardness, 1.25; Gravity, 1.5. Liquid when hot, sectile when cool, tar-like and amorphous.

PETROLEUM (Rock Oil). Composition, C, H, O. This differs with localities and in different strata in the same section. Petroleum is found in the rocks of all ages from the Silurian to Tertiary, usually the deeper the strata the better the oil. The Tertiary oils have a heavy asphalt base, rendering them unsuitable for refining.

(B) MINERAL COAL

There is every grade of coal from Peat to Graphite, the deeper the coal is imbedded the purer the carbon, while surface or Tertiary coal contains impurities and volatile matter. The reason for this is that the coal in the older formations has been subjected to such pressure from overlying strata that the impurities have been squeezed out; the heat of the earth too tends to drive off volatile matter. This is proven by the alteration of Bituminous coals in New Mexico to Anthracite by the intrusion of porphyry dikes. The following are the principal Mineral Coals:—

LIGNITE (Lignum-Wood). Composition, C 35 to 45%
Volatile matter, (O, H & N S) 45 to 60%; Ash and other impurities, 7 to 15%.

Remarks: Lignite Coal is so named because formed from buried wood so shallow and so little compressed and baked that the grain and other characteristics of original wood may be noted in the coal. Lignite coals ignite easily and are quickly consumed.

BITUMINOUS (Soft Coal). Composition, C 55 to 65%,
H 10 to 20%, O 15 to 25%, N 3 to 5%, S 1 to 2%, Ash 3 to 8%.

Remarks: Bituminous Coal carries a greater percentage of fixed carbon and less volatile matter than Lignite.

ANTHRACITE (Hard Coal). Composition, C 75 to 85%,

H 2 to 5%, O 6 to 10%, Ash 7 to 10%.

Hardness, 2 to 2.5; Gravity, 1.61; Fracture, conchoidal; Burns with a feeble blue flame. Volatile matter ranges from 5 to 8%. Difficult to ignite, but once started a fire lasts and emits little smoke. An intermediate coal between Anthracite and Bituminous Coal is sometimes called *Semi-Anthracite*.

Silica (Si) Minerals

72. The element Silicon (Si) is never free. It is next in abundance in the Earth's crust to Oxygen, with which element it combines to form Quartz, Flint, etc., called Oxides of Silicon. Flint is uncrystallized silica, while Quartz is nearly always crystalline in structure.

There are a number of varieties of Quartz which have the same physical and chemical properties, only differing in color, which is due to the presence of other elements as impurities.

QUARTZ. Composition, Si 46.67%, O 53.33%; Hardness,

7; Gravity, 2.5 to 2.8; Color, white to yellowish.

Luster, vitreous, transparent to opaque. The following *Gem Stones* are varieties of quartz, viz:—

- (1) Rock Crystal—white.
- (2) Rose Quartz—pink.
- (3) Amethyst—purplish.
- (4) False Topaz—yellowish.
- (5) Chrysoprase—apple-green.
- (6) Carnelian—bright-red.
- (7) Agate—cloudy.
- (8) Onyx—various colors.

(9) Bloodstone—green with blood-colored spots.

SILICATE MINERALS

Silicates are compounds of Silicon, Oxygen and another element. The silicates of the metals have already been described. The following are the principal Gem Stone Silicates, viz:—

GARNET. Composition, Si 36%, Al 20%, Fe and O 43%.
Luster, vitreous; Color, various from red to black.

TOURMALINE. Composition, Si 39%, Al 30%, Mg 8%, B, Fe, O, etc. Hardness, 7.5; Gravity, 3;
Color, blue-brown to red.

TOPAZ. Composition, Si 16%, Al 55%, Fl, etc. Colors, various, yellow, white, bluish, red, etc.

COMMON SILICATE ROCKS

PYROXINE. Composition, Si 55%, Ca 23%, Mg 16%, Fe, Mn, O. Hardness, 5 to 6; Gravity, 3.5; Color, greenish, white to dark.

ANDESITE. Composition, Si 59%, Al 25%, Ca 7%, Na 7%. Color, whitish, grayish to bluish; Hardness, 6; Gravity, 2.7.

HORNBLENDE. Composition, Si 48%, Ca 10%, Mg 13%, Mn, Fe and O. Color, black to greenish; Hardness, 5 to 6.1; Gravity, 3.2.

What Are the Gangue Minerals?

73. Metal Minerals are found in veins or lodes mixed with other minerals called Gangue or vein mineral. In metalliferous veins, the Gangue matter is usually more or less banded or arranged in streaks or layers and a determination of the different gangue minerals and relative proportions, is often very desirable.

The following are the minerals usually associated with metal mineral veins:—

- (1) Quartz.
- (2) Calcite.
- (3) Dolomite.
- (4) Barite or Heavy Spar.
- (5) Fluorite or Fluor-Spar.
- (6) Iron, oxide or pyrite.
- (7) Talc.

Other minerals sometimes found either in or associated with veins are:—

- (a) Porphyry.
- (b) Granite.
- (c) Andesite.
- (d) Rhyolite, and other igneous rocks.

These minerals have already been described, and this knowledge will enable the reader to name the gangue minerals in most any ore and form an estimate of the proportions of each constituent.

How to Make Practical Application of Physical Properties

74. We have briefly noted Physical Properties common to minerals and have grouped and classified the most important according to their physical properties and Chemical proportions. Such lessons are mainly theoretical and in order to make this knowledge of much value it must be put into practice. Any one with mineral specimens of determined purity can test them by all the physical properties named in the table for that particular mineral, and verify their characteristics as well as the identity of the mineral itself. This is the usual course in the study of mineralogy.

Having the answer to the problem in the mineral itself duly determined, it is relatively easy to work backwards to prove the elements that enter into its composition. In field practice, however, the conditions are exactly reversed. The mineral specimen found *is* the problem and the answer must be worked out by a regular process and the answer must come as a result of careful examination and patient work. The following is suggested as a working plan in the determination of a mineral:

An unknown mineral is submitted for test. We examine it and note its Luster is metallic. Note on a piece of paper, "Luster Metallic." Next we note its color, as "lead gray," and Streak the same. Its general appearance indicates it is a Sulphide of some kind. Note "Sulphide" on record paper. Now examine its hardness. It is soft, the finger nail scratches it slightly and a copper coin will scratch it. Note its hardness as "under 3," perhaps 2.5. Next note its weight in the hand, comparing it with a piece of quartz or granite of similar size whose known Gravity is about 2.5. The specimen appears about three times heavier. Note "Gravity, say, 7." Take the point of a pocket knife and see if you can cut it. Does it powder, or cut off in flakes? If the latter, note "Sectile." Break it with a hammer, if you have one, if not take another rock and strike it. Does it fracture easily? What kind of a surface does it leave, smooth or uneven? If "*uneven*" examine and note if surface has shell-like cavities and projections. If so note "Conchoidal Fracture." Next note the crystals with the naked eye and with a lens. Can you detect angles and faces of cubes? If so mark it "Crystals Isometric." Before leaving it take a small splinter of the mineral and subject it to the candle flame. If it melts note "Fusibility 2 or under." If you have familiarized your-

self with the physical properties of common minerals, you can readily name the mineral. From our examination three things stand out prominently: (1) It is very heavy; its weight must be due to its metal content. We infer it is either a Gold, Silver or Lead mineral. Let us see what Gold mineral it might be. A Gold Telluride is the only one that has any of the characteristics named. No Telluride mineral has Isometric Crystals, so we eliminate that from consideration. We must now determine whether Silver or Lead mineral. Lead minerals are nearly all brittle and powder under the knife point. This does not, but cuts off in flakes, so we eliminate Lead from the problem and decide it is a Silver mineral. We have already decided it is a sulphide from its appearance and the sulphur fumes in the candle flame. There are several Silver minerals that have sulphur in their composition. Is it Argentite? Now look at the physical properties named for that mineral; you find on comparing with your notes that they correspond. It is *Argentite*; the problem is solved. Note the Composition, Ag 87%, S 12%. Chemical analysis is unnecessary. Many other minerals are as easily determined by this same method. We took a common mineral and the problem was not so difficult, but in actual practice it is not so easy, especially in the field. Pure minerals are rare, but even in a mixed mineral some crystalline particle may often be observed which serves to distinguish it by physical properties.

In concluding the subject of Mineralogy, the author can not forbear again urging the necessity of securing true mineralogical specimens from some reputable dealer in minerals, especially such as you are most interested in, as comparisons can be quickly made and you will soon become

so familiar with the common minerals as to be able to classify them off-hand.

How to Estimate the Value of Ores

An ore is usually a mixed mineral, often made up of several minerals together with gangue minerals, the whole constituting a vein filling.

Suppose in a pound average sample of a copper ore that one-tenth of the mass is made up of Azurite and Malachite, usually surface ores. By referring to the tables you will see Malachite and Azurite when pure average about 70% copper.

One-tenth of a ton is 200 pounds; at 70% copper would be 140 pounds copper metal to the ton. Multiplying by 15 cents, value of one pound of copper, would give an estimate value of \$21 per ton of ore.

PART IV

**MINERAL
DEPOSITS**

Part IV

MINERAL DEPOSITS

1. Under the subject Mineralogy, we learned that all except those found native, are compounds of two or more primary elements, usually crystallized into geometric forms, with a definite proportion of each combined element. It was also shown that such mineral crystals result from the processes known as *Fusion*, *Vaporization* and *Solution*; the elements separating out and combining in accordance with natural laws.

It must not be assumed that all minerals occur in a pure state; except in a few instances, mineral deposits of commercial importance are found associated with the more common earth minerals known as *Gangue*, so that the result is a mixed mineral, and this is what the practical miner, as a rule, has to deal with in the field.

What Are the Relative Proportions of the Elements?

2. Of the eighty elements that make up the earth's crust, six compose nearly 95% and seven additional swell the amount to 99% of the crust. Sections of the crust have

been analyzed and an estimate made of the proportions of the most abundant elements, as follows:—

Oxygen	45 %
Silicon	25 %
Aluminum	10 %
Iron	8.5%
Calcium	6 %
Potassium, Sodium, Carbon and Magnesium.....	3.5%
Sulphur, Hydrogen, Chlorine and Nitrogen.....	1.5%
67 Other Elements.....	0.5%
Total	100.00%

This table shows that sixty-seven elements, which include all the “precious metals,” comprise only one-half of one per cent of the earth’s crust. Some authorities estimate the precious metals compose less than one part of one thousand, or less than one-tenth of one per cent of the mass.

These are only approximate proportions, but whether accurate or not, it is quite plain that minerals of commercial value are rare, although the elements are everywhere present in finely disseminated particles. These can only become of importance when concentrated by nature’s processes into what are called MINERAL DEPOSITS. For example—Gold is one of the rare elements, yet it is found in the rocks of all ages, and in the waters of rivers, seas and oceans. Analyses of ocean waters show 40 to 50 miligrams (about 1-20 grain) to the ton of water. This may seem trifling, but when it is considered that the seas cover three-fourths of the earth’s surface, and contain multiplied millions of tons, the total amount of gold held in suspension or in solution is enormous, and if it could all be extracted economically, gold would be too abundant for coinage into money.

Since the precious mineral elements are everywhere present in such small proportions, and only occasionally found in commercial quantities, it is important to know nature's processes of segregating and collecting the rare elements into what are known as Mineral Deposits.

What Is the Origin of Mineral Deposits?

3. The genesis (beginning) of mineral deposits is a subject not fully understood, hence cannot be regarded as an exact science, and it becomes necessary to theorize in our endeavor to ascertain the truth.

To the practical man, theories may often appear useless, but in the absence of positive knowledge this is our only recourse. We are not without facts as to the occurrence of mineral bodies, but the variety in form and structure of such deposits throughout the world has resulted in several theories as to their origin, each of which is based on evidence more or less convincing in particular cases.

A knowledge of these origin theories is important inasmuch as they represent the most advanced thought on this subject. And from the further fact that the successful development and valuation of a mine requires a definite idea of the geologic forces, the chemical and mechanical processes which combined to produce the mineral deposit. A knowledge of these fundamental principles enables a practical mining man to formulate a definite scientific plan of operation without which everything must be left to "chance" and almost certain failure.

There are two general theories as to the original source of the metallic elements, viz: —

(a) *Surface Origin*,—from sea water, and

(b) *Subterranean Origin*,—from molten interior of the earth.

Both of these grow out of the theories as to the origin of the earth itself. (See Nebular and Meteoritic Theories.)

What Is the Sea Water Theory?

4. This theory, in general, supposes that all the metallic minerals in or upon the earth are derived from the waters of the seas. If we accept the Nebular Hypothesis of the origin of the Solar System, we may believe—

(a) That in the “beginning,” all matter was in a gaseous state, and

(b) That as the earth cooled so far as to form water on its surface, this hot primeval ocean held in solution (dissolved) all the metallic elements, condensed from original gaseous matter ;

(c) That the metallic elements were separated out by living organisms, or through their dead bodies, the accumulations of which brought the metallic elements within the sedimentary rock strata, where the circulation of underground waters, through previously formed fissures and cavities, formed the mineral deposits we find within the earth today.

(d) That when metals are present in igneous rocks, they were fused from sediments, and that in the process of the ages all rocks have been partly or completely fused and worked over many times, so that in brief all mineral deposits near enough to the surface to be reached by man contain only such metallic elements as were originally dissolved in the sea water.

Let us examine the evidence to sustain this belief:—

(1) This theory is based upon the demonstrated fact that sea water does contain all the metallic elements. (See

Par. 2.) But this fact does not prove that these elements were not first washed from the igneous land rocks. In fact presence of gold, for instance, in ocean waters adjacent to metalliferous regions like Australia and the Pacific Coast of North America, in greater percentage than elsewhere, seems to be against this theory.

(2) Science is agreed is agreed that lime rocks are formed from the shells and bones of sea animals, and since the base of limestone is the metallic element Calcium, it is argued that all other metallic elements might well be derived in a similar manner. But this claim does not take into consideration that the mineral existed before the animal, and the same objection holds against the original source of quartz, as the result of secretions of sea animals.

(3) The presence of metallic elements in sedimentary rocks, it is claimed, tends to prove sea water origin. This claim is not given much credit, as it is equally evident that the insignificant percentage of metallic elements in stratified rocks might easily be derived from erosion and corrosion of igneous rocks.

(4) Some deep mines that occur near oceans have been found to contain salt water, notably in Australia, and the presence of chloride minerals in many places tends to prove at least some connection between sea water and mineral deposits found in the earth's crust.

What Is the Igneous or Subterranean Theory?

5. Founded also on the theories of the origin of Solar System is the claim that all metallic minerals have their source within the earth. Those who support the subterranean theory claim:—

(a) That as the earth cooled, those elements like iron,

cobalt, nickel, platinum, etc., that fuse only at very high temperatures, condensed from a gaseous form to liquid. On further cooling they became plastic and formed a nucleus of the globe, around which in succession the other elements, lower in the scale of fusibility, gradually arranged themselves in the process of condensing, until all the solid elements were included in the sphere. Lastly water was formed by the union of oxygen and hydrogen, leaving behind the atmosphere, a mixture of gases somewhat as we find it today.

Let us see what evidence there is to sustain this subterranean theory.

(1) The weight, or specific gravity of the earth as a whole, as computed by scientists, is about three times that of the outer crust known to man.

(2) The heavier and difficultly fusible metals are present in greater abundance in the primitive, crystalline rocks.

(3) The undisputed and otherwise unexplainable fact that the earth is a great magnet, which might well result from a core within the earth of the magnetic minerals,—iron, etc.

(4) The vapors of volcanoes are laden with metallic elements and the waters from hot springs are charged with dissolved mineral matter.

Unlike the claims for the sea water theory, the evidences above named are not open to such serious objections, so that it appears plain that the immediate source of metallic metals usually found in veins is within the earth, although they may have been derived partially, or wholly, from underground passages leading to the seas as the primary source.

Conclusions from the Evidence

6. Each of the theories has the support of learned authorities, but the igneous theory appears to be worthy of the most consideration on account of the preponderance of the evidence in its favor; but whether the original source of metals is within the earth or not, it would be contrary to the known economy of nature to thus lock up the metallic contents permanently. So, assuming that the metallic burden of sea water was derived from the igneous rocks, nature's processes must, in some way, return the metallic elements to the solid crust, as surely as the ocean water returns to the land in the form of rain.

How Are Mineral Deposits Formed?

7. Since metallic elements are everywhere present, but in such minute quantities as to be valueless, it must be apparent that these must be collected and segregated by nature's forces in order to be of use to man. In the animal and vegetable kingdoms, organic matter separates out into groups or families, in accordance with natural laws, and in the mineral kingdom there is a similar tendency. Thus water is ever moving, collecting and aggregating on its way to the great "mother of waters"—the ocean. We explain this in obedience to the great law that,—"*Water seeks its level,*" and it is natural to assume that there is a similar movement of metallic elements to separate out and aggregate each after its kind. We can only explain this by saying that "*like attracts like,*" and the result is a concentration of metallic elements into what we call mineral deposits.

What Are the Concentrating Agencies?

8. There are a number of forces which have been acting throughout the ages collecting the widely distributed metallic

elements into mineral deposits for the use of man. These forces act singly and in combination, but they may nevertheless all be classified under two heads, as follows:

(1) Mechanical Agencies.

(2) Chemical Agencies.

(1) *Mechanical Agencies* include forces that operate in obedience to natural laws, such as gravity, mineral attraction, etc. They produce no real change in the elements themselves. The formation of placer beds by glacial action, and by the movement of water from the heights to basins or river channels below, illustrate this mechanical action. The specific gravity (See Page 111) of the metals usually found in placers, being greater than the associated elements, the lighter are carried along with the current, while the heavier lag behind and tend to settle and accumulate in favored spots to form placer beds. There is also a kind of chemical action which assists the mechanical, but this will be explained later.

(2) The *Chemical Agencies* are more complex, and hence not so easily explained or understood. This subject properly belongs to Physics and Chemistry, but inasmuch as ore deposits are due largely to chemical agencies, a few elementary principles are necessary to understand the formation of ore deposits. These agencies while called Chemical, involve physical forces to some extent, but may be classified as follows:

(a) Vaporization,

(b) Fusion,

(c) Sublimation.

(d) Solution.

9. (a) *Vaporization* is the process of changing a liquid to a gas, or vapor. A simple process, familiar to all, is the

change of water to vapor, as in steam due to the agency of heat. When water is exposed to the influence of the atmosphere and the sun's heat, it passes slowly into the gaseous state, leaving behind its mineral burden, and the process is called *Evaporation*. Beds of salt, soda and some gypsums are formed by this simple natural process.

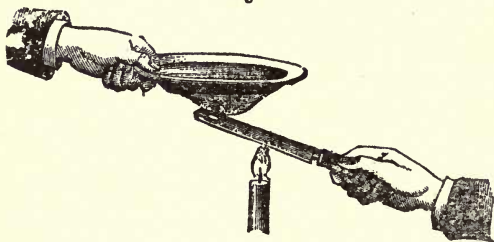
When a liquid or molten metal is subjected to the proper degree of heat, it also passes into a gaseous state, and it is then said to *Volatilize*. All known elements are volatile at temperatures considerably above their respective fusing points.

10. (b) *Fusion* is a process that results when mineral elements are subjected to the degree of heat necessary to melt them, as in smelting. When fusion takes place, the metallic elements separate out from the mass, each after its kind, or as an alloy, and if conditions are favorable upon cooling mineral crystals will form. It is believed that the heat of the earth, in the Molten or Flowage Zone, is sufficient to fuse all matter, and as a result the metallic elements are segregated and concentrated out of the molten mass. The eruptive forces expel this mineral matter through fissures in the crust, as in the case of the minerals magnetite and pyrrhotite, to fill such cavities with ores. It is not certain that any of the precious mineral deposits are formed by the direct process of fusion, but many so-called "blow-outs" of metallic minerals and some placer nuggets may perhaps be traced to such an origin. Few veins are thus mineralized, however.

11. (c) *Sublimation* is the process by which metallic vapors are condensed and solidified, by coming in contact with a cool surface, when a coating or deposit is formed, called a sublimate. It is a purifying and concentrating process combined, and is analagous to distillation in liquids.

A familiar example illustrating the processes of fusion, volatilization and sublimation is shown in Fig. 46. A bit of sulphur is placed on a knife blade held over a candle flame in such a way as to avoid setting fire to the sulphur; the sulphur first melts and forms a liquid (*fusion*), which grows smaller and smaller from arising vapors (*Volatilization*); if a cold plate is held above the escaping sulphur gas, it is deposited there as "flowers of sulphur" (*Sublimation*), and the element thus condensed is called a *sublimate*. This is purely a physical change, but if the sulphur is ignited (burned) an entirely different process ensues. Now sulphur

Fig. 46



The sulphur that we cause to *evaporate* remains sulphur (physical phenomenon).

is classed as a Non-Metal, but it serves to illustrate the processes named as well as a metal; when it is remembered that all metals are volatile at appropriate temperatures, and that the heat of the earth's interior is sufficient to change every element into the gaseous state, we may understand how metallic vapors escaping through open fissures in the earth's crust and coming in contact with cool surfaces may form a deposit or sublimate of the metals to constitute an ore body. Examples are not wanting in nature of minerals deposited by sublimation. Metallic crusts are thus formed in cracks or fissures adjacent to expiring volcanoes; sixteen different

metals have been extracted from the vapors arising from the volcano Vesuvius. No ore deposits can be formed in an active volcano, because of the absence of a cool surface to condense the metallic vapors. Many so-called "ore chimneys" in veins are believed to have been formed by sublimation.

12. (d) *Solutions*. All metals are more or less soluble in acids and alkalies, especially when the metallic particles are in a finely divided state. The earth's crust contains many acid and alkali minerals, and these are dissolved or rendered soluble by water circulating through fissures and cavities in the Oxide Zone, which solutions in turn, assisted by the atmospheric gases, attack the metallic elements to render them soluble. Heat too assists in dissolving mineral elements, and thus the process of *Solution* continues and tends to concentrate the dissolved mineral matter into cavities or fissures. It requires, however, another process to separate out the metallic elements from the solution to form ore deposits which is known as *precipitation*.

Precipitation. This process is a literal "throwing-down" of the metallic burden of a solution into a solid form. A precipitant may be an element or a compound, different from that contained in the solution itself, as a solid, liquid or gas. Electricity, which is everywhere present, acts as one of the most powerful precipitants.

Precipitation of metals from solution is analagous to sublimation of metallic vapors. A simple experiment to illustrate precipitation is to dissolve a bit of silver metal in nitric acid, after which add a little common table salt

(Chloride of Sodium), when a white substance settles out, or is "thrown down" as a precipitate, known as a *silver chloride*.

Some metals precipitate other metals from their solutions. Thus silver is thrown down by copper, copper by iron and lead by zinc. Hot metallic solutions may often be precipitated by cold water, and cold metal solutions may likewise be precipitated by hot water. The water of many mines carries considerable copper in solution. In the early days of copper mining, bright fellows bought waste water from such mines for a mere pittance. They precipitated the metallic copper by running the water over tin cans and scrap iron; in this very simple and effective way they made much money. The water in many copper mines has its metallic content precipitated on iron pyrites to form native copper.

Laboratory experiments have proven that gold is also precipitated from solutions on iron pyrites after a long period. Gold is also precipitated from alkaline solutions (Cyanide) by zinc and electricity.

If these principles are borne in mind, the concentration of metallic elements to form ore deposits will be more readily understood.

When it is considered that all the reagents known to science, and perhaps some about which nothing is known, are found in nature's vast laboratory, and that these processes have been at work throughout the ages concentrating the metallic elements from the great earth mass to form ore deposits for the use of man, we may realize, in part at least, how important it is to understand nature's laws and work in harmony therewith in all mining operations.

POPULAR THEORIES AS TO THE GENESIS OF ORE DEPOSITS

13. Ever since lode mining came into existence, man has striven to find out nature's secret processes of mineralizing veins. The great varieties of ore deposits have given rise to several theories. The earlier of these have now been practically discarded, but there are many who still cling to these primitive ideas. Thus every mining man should be familiar with the merits and inconsistencies of each in order to keep abreast of the times, as well as to avoid the most common errors in mining.

These different origin theories may be classified as follows:

- (1) Contemporaneous Formation.
- (2) Igneous Injection.
- (3) Electric Currents.
- (4) Descending Waters.
- (5) Sublimation.
- (6) Lateral Secretion.
- (7) Ascending Waters.
- (8) Replacement.

(1) What Is the Theory of Contemporaneous Formation?

14. This is a theory held by early writers, and the supposition was that the veins were formed and mineralized at the same time the enclosing rocks were formed, and that rich mineral deposits were a mere incident or accident. This theory may be accepted as regards the formation of sedimentary mineral deposits, but so far as ore deposits in veins

are concerned it is contrary to all known science and may be dismissed from further consideration.

(2) What Is the Theory of Igneous Injection?

15. This theory assumes that all veins were formed and mineralized by injection of igneous matter from below, and that this molten magma contained all the metallic elements found in ore deposits. This belief proceeds from the proven fact that all igneous rocks contain metallic elements in greater or less degree. When we consider, however, the banded structure of many veins, and the irregular occurrence of ore in shoots or pockets within the vein material this theory is unsatisfactory and is now generally discarded by scientists. While there may be instances of igneous injection of metallic minerals into veins, they are rare and are not well sustained by evidence. Therefore this theory does not merit serious consideration.

(3) What Is the Electric Current Theory?

16. The Electric Theory had strong support a half century ago, but the later authorities have raised serious objections to it. There is, however, a solid foundation for this theory in the fact that the earth is a great magnet, and as friction is known to develop electricity, it appears reasonable that earth movements developed powerful electric currents during the period of formation and filling of veins.

Electric currents have been proven to exist in veins today, and this is recognized as a most effective agent in metallurgy, as a precipitant, which makes it seem probable that this is one of the great natural forces within the earth to "throw down" the metallic elements from mineral solutions, but there is little or no evidence to sustain the belief that the

electrical forces carry the metallic elements into or through the veins.

(4) What Is the Theory of Descending Waters?

17. This theory follows in part the supposition that all metals are derived from the sea water, and that the metallic burden was deposited in fissures and cavities from the waters flowing over them. There are instances of minerals occurring in the sedimentary rock fissures, like lead, zinc, etc., that may have been thus formed, but deposits in igneous or metamorphic rocks show no evidence of having originated from descending waters. This theory is also open to the serious objection that metallic elements would be deposited by surface waters in as great abundance in regular sedimentary rock strata as in fissures. There is, however, some evidence to show that descending water from rains and melted snow, charged with atmospheric gases, do enter fissures and tend to concentrate the metallic elements. This fact is proven by the deposit of ores on the down-stream wall of fissures in greater abundance than elsewhere, but such metallic elements appear to have been derived from the eroded surfaces of mineralized veins, or from disintegrated igneous rocks in the vicinity rather than from the sea water.

Many mining men cling to the descending water theory, and the local enrichment of veins, often found near the permanent water level, are generally believed to be due to concentration of the metallic elements by descending waters, leached from minerals above. But this is a secondary process, and it utterly fails to prove surface waters as the *original source* of the metals found in veins and cavities.

(5) What Is the Sublimation Theory?

18. According to this popular theory, veins are mineralized by volatilization of metallic substances within the earth. The arising metallic vapors coming in contact with the cooler crust above, form sublimates or crusts of the metals within the veins, which may later assume the form of native metals. Several authorities contend this is the true solution of the origin of most ore deposits, and indeed strong evidence is not wanting to substantiate this theory. The admitted fact of the occurrence of ore bodies within veins in "chimneys," "shoots" and "pipes of ore" is difficult to explain on any other hypothesis. The known intense heat of the earth's interior, the proven volatility of all metals at high temperatures, and the fact that metallic vapors condense and form sublimates in coming in contact with cool surfaces, are additional evidences to substantiate this theory.

The theory of sublimation is applied to all the so-called precious metals, as having been deposited within the open and porous sections of veins previously filled with gangue minerals. It is not claimed, however, that the vein filling such as quartz, spar, etc., are themselves deposited by sublimation.

(6) What Is the Theory of Lateral Secretion?

19. This theory is based upon the admitted fact that all country rock contains metallic substances in finely divided particles. These are assumed to be collected by waters, charged with atmospheric gases, circulating through the more or less fractured rocks to concentrate the metallic elements in cavities or porous sections of lodes. This theory is reasonable and for the last quarter century has been quite generally accepted. But recently the trend of scientific opinion has turned against the lateral secretion theory. The chief

objection is founded on the insignificant metallic contents of country rocks from which concentration might reasonably take place, and if metals were so derived, all veins, and perhaps dikes, should be uniformly mineralized. The practical mining man knows that this is not the case.

(7) What Is the Theory of Ascending Waters?

20. This is a most popular modern theory. In its earlier form the supposition was that veins are formed by minerals dissolved out of the adjacent rocks, the chief portion of which is derived from great depth and deposited by hot waters circulating through fissures. The modern application of this theory simply undertakes to account for the deposit of metallic elements in the gangue minerals of veins previously formed by igneous action. It is well known that heated mineral waters possess great solvent properties, and the expansion due to heat and pressure below causes the water charged with mineral matter to rise and circulate through the portions of veins offering the least resistance. As the solutions cool in their upward course, the metallic burden is deposited in the gangue matter. The presence of metallic mineral deposits in the vicinity of hot springs seems to confirm this theory, although such hot springs, like craters of volcanoes, do not have metals deposited on their walls, as both fusions and solutions must cool before sublimation or precipitation can be effected.

(8) Theory of Replacement

21. This is the most modern theory advanced and has many supporters. It is somewhat a modification of the Lateral Secretion theory, and only differs from it in the supposition that the particles of mineral dissolve out of the country rock have substituted in their place mineral matter from the

solvents circulating in the vein itself. This interchange or substitution of mineral matter from veins for those leached out of the wall rock is assumed to continue until it results in a deposit of ore. Certain irregular ore bodies no doubt are thus formed, but that any veins are so mineralized is extremely doubtful.

What Conclusions May Be Drawn From These Theories?

22. From this apparent conflict of opinion amongst the authorities, it might be thought the ordinary mining man has little hope of arriving at a satisfactory conclusion.

Certain principles, however, stand out boldly as a result of our examination of these several theories so that we may sum up the evidence and arrive at a verdict. The following points are fairly well established:

(1) The immediate source of metallic ores is within the earth.

(2) Metallic elements are everywhere present, but require to be concentrated by nature's forces before workable ore deposits are formed.

(3) Metallic vapors arising from the earth's interior are either absorbed by circulating waters or deposited by sublimation.

(4) The open and porous portions of veins and rocks are mineralized by metallic gases and by solutions circulating through them.

(5) Surface waters charged with atmospheric gases, precipitate the elements from hot metallic vapors and solutions to form ore deposits.

(6) No single theory can be applied to all forms of ore deposits, as two or more agencies are usually present and acting to concentrate metallic elements into ore deposits.

Ideal Section Illustrating Origin of Ore Deposits

23. It is difficult to draw a picture representing the earth's crust and the several processes heretofore described, resulting in ore deposits, without also drawing heavily on the imagination. However we have a few demonstrated facts to guide us, and with these as a skeleton we may build upon it a framework in accordance with the principal theories of ore deposition heretofore described.

Fig. 47 represents a section of the earth's crust showing the three Zones. The Oxide extending from the surface to water level, represented by the bed of the water course at 2. In this Zone, as its name indicates, the rocks are fractured and fissured to such an extent that the surface waters and atmospheric gases circulate throughout them down to the water level. The Sulphide Zone is seen extending from the Oxide at B to the Flowage at C. In this Zone the fractures are smaller and the earth's heat greater. The Molten Zone is seen extending from C to D. Here the temperature and pressure are great, and fractures hair like. A, B, C, D, represents a Fissure vein in process of filling. The lines 1, 2, 16, 17 and 18 represent channels through which surface waters and atmospheric gases find their way, dissolving out the soluble mineral elements and depositing their burden into the great central trunk vein. The lines at 2, 3, 4, 5, 12, 13, 14 and 15, show assumed channels for the passage of warm water solutions, also leading to the main trunk. The lines 6, 7, 8, 9, 10 and 11 also show theoretical channels for vaporized waters and metallic gases generated by heat and pressure, which by reason of their lesser specific gravity and eruptive forces there present take an upward course through the Sulphide and into the Oxide Zone. These coming in contact with cooler mineral solutions from above would have

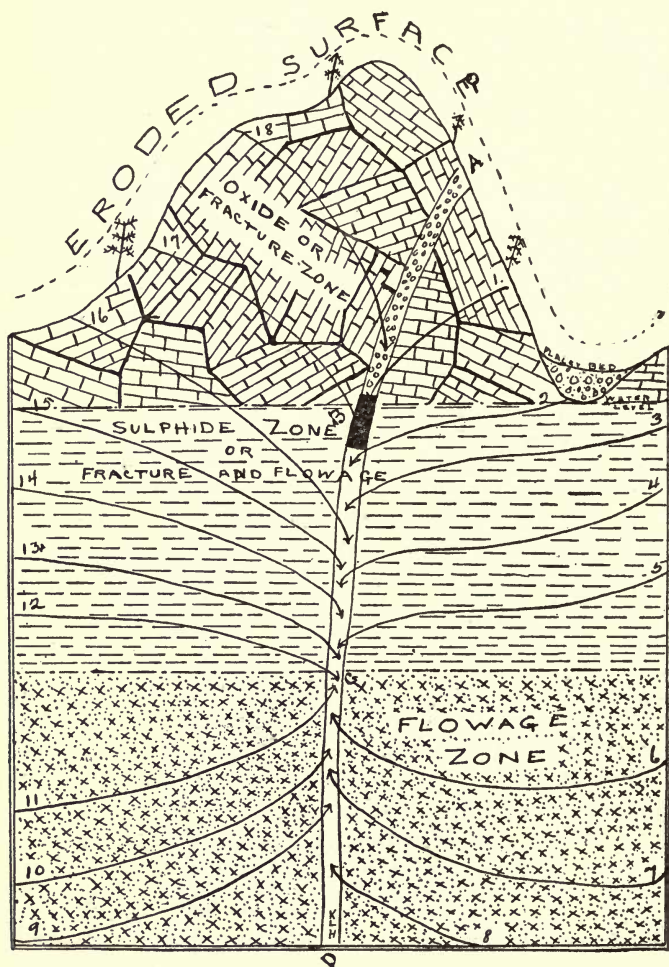


Fig. 47. Ideal Section Illustrating Genesis of Ore Deposits.

their metallic contents deposited by sublimation or precipitation in the more open and porous gangue minerals of the vein above. On the contrary, the surface waters charged with dissolved minerals in meeting an ascending current would tend to precipitate their metallic burden also, and these processes continued throughout vast ages result in deposits of ore.

The shaded section of vein at B represents the "Zone of Secondary Enrichment," resulting from the leaching of ores above and the precipitation of their metallic burden at the water level. Within the vein above the water level occur oxides, sulphates, chlorides and carbonates of the metals, which result from the alteration of sulphides by coming in contact with the oxygen of the atmosphere and with the descending waters.

Below the water level all minerals contained in veins are sulphides. Below point C, or in the Flowage Zone, we may only guess whether there would be a different ore, or no ore at all, since no shafts have as yet penetrated this Zone. However, it seems certain with the known increase of temperature that metallic elements would likely be in a molten or gaseous state.

Laboratory experiments have demonstrated the principles upon which the theories relating to ore deposits are based, and since the same unchanging laws prevail everywhere, we are reasonably sure that similar reactions are taking place in nature's vast laboratory within the earth. At best, man can only imitate nature, and it is possible that there are agencies and processes as yet undiscovered and which if fully understood would make clear many things in regard to the formation of ore deposits that are now somewhat clouded.

What Is Nature's Preparation for Mineral Deposits?

24. We behold a plan or design in everything in nature, and the formation of ore deposits is no exception to the general rule. It must be apparent that if the earth were one solid uniform body no mineral deposits could be formed. Under the subject Geology we learned that countless ages were required to prepare the earth for man, and it is evident that the same "Supreme Intelligence" has made a somewhat similar preparation for the reception of ore deposits. Earth movements have fractured the crust, producing fissures and cavities in which to concentrate metallic minerals. Complex faulting and igneous eruptions have permitted metallic vapors from below to penetrate these open spaces in the crust, which fissures also serve as channels for the circulation of underground waters to concentrate the metallic elements into ore deposits. These processes have continued throughout the ages and doubtless will not cease until the end of time.

How Are Mineral Deposits Classified?

25. Mineral Deposits are so varied in form and origin that it has been difficult for the authorities to adopt a standard classification. Many different schemes have been proposed, but it is generally agreed that the only natural basis of classification is that of *origin*. If we know the natural agencies that have caused a mineral deposit we are able to estimate its probable value and extent, and thus be able to formulate a practical plan for removing the mineral.

For example: If a mineral deposit has all the characteristics of a fissure vein filling, its future may be forecast with a fair degree of accuracy by applying the rules governing fissure veins.

Classification of Mineral Deposits

I. REGULAR DEPOSITS.

(a) BEDS (STRATIFIED DEPOSITS).

- (1) Sedimentary Deposits.—Residue from Evaporation.
- (2) Placer and Beach Deposits.—Mechanically deposited by water.
- (3) Coal Measures.—Vegetable matter enclosed and compressed by Stratified Rocks.
- (4) Petroleum.—Buried Organic Matter, Condensed and Refined.

(b) VEINS (UNSTRATIFIED DEPOSITS).

- (1) Fissure Veins.—Regular Walls of Similar Rocks.
- (2) Contact Veins.—Unlike Walls of Igneous and Aqueous Rocks.
- (3) Gash Veins.—Filled Surface Cracks, Irregular in Strike and Dip.
- (4) Segregated Veins.—Irregular Form. Follow Folds of Enclosing Rocks.

II. IRREGULAR DEPOSITS (*Without Walls or Definite Definite Form*).

- (1) Chamber Deposits.—Filled Cavities of Uncertain Origin.
- (2) Impregnation and Stockwork. — Mineralized Veins and Wall Rock.
- (3) Fahlbands.—Mineralized Rock Strata.

The above outline includes all the deposits of especial interest to the mining man, and they will now be considered in the order named:

Beds or Stratified Deposits—What Are They?

26. The origin of mineral deposits occurring in regular layers between sedimentary rocks is not difficult to understand. They all lie parallel with, and conform to, the bending and folding of the enclosing rocks, which fact often throws the deposits into arches or saddles, called *Anticlines*, while the lower folds form troughs or *Sinclines*. (See Figs. 29 and 50.) Such deposits were all formed during the same period as the enclosing rocks, and are of surface origin entirely. Stratified Deposits can have no regular walls like veins, so the upper stratum is called a "roof" and the lower stratum is called the "floor."

How Are Bedded Deposits Formed?

27. Such deposits are either formed by sediments washed down from the heights like sedimentary rocks, or from the evaporation of the water from mineral solutions, leaving behind the solid mineral elements. Salt-beds are formed in basins, formerly a part of the ocean. The waters vaporized and passed into the atmosphere, leaving the residue of salt chemically known as *Chloride of Sodium*. These beds when covered up for ages and brought into contact with the heat of the earth, or igneous rocks, are crystallized into the mineral Halite. Some limestones and gypsums are thus formed from dissolved mineral matter, washed into basins by waters drying up and leaving mineral beds behind, which may be later crystallized.

What Are Placer Deposits?

28. There are three kinds of Placer Deposits, differing only in occurrence, which are concentrated mechanically by the action of water on the gravity principle, viz :

- (a) *Stream Deposits,*
- (b) *Ancient River Deposits,*
- (c) *Beach Deposits.*

The metals usually found in placers are Gold, Tin and Platinum, these only being able to resist the erosive and corrosive elements. The high specific gravity of these metals favor their concentration into beds, the lighter elements washing off leaving the heavier behind. Some recent writers claim that placer minerals are formed, in part at least, from metal solutions. (See Par. 32).

29. *Stream Placers* are those found in present day water courses and are of comparatively recent origin, dating from the Tertiary Age. Streams in all mineralized districts contain more or less placer minerals in the form of nuggets, grains or fine metallic flakes. These have been carried to their present position by moving waters or glaciers, from eroded outcroppings of mineralized veins, or from disintegrated igneous rocks.

The character of the placer metal is said to indicate its origin. That is, if the native metal is coarse grained and rough edges, it indicates the source is near at hand in well mineralized ledges; but if the metallic particles are fine and flaky with well rounded edges, it indicates the metallic particles have traveled far, and their origin is possibly due to the action of Glaciers. (See Glaciers.)

The placer metals are usually found mixed throughout the pebbles and sands, but the richer deposits are found near

bedrock. The most favorable catchment basins are formed where the stream is somewhat level.

In Fig. 72 is shown an ideal placer deposit. The bed-rock A-A is an upturned schist, into which are formed cavities that catch the heavier metallics that sift down through the sand and gravel of the stream bed. At B is what is called a "pot-hole," which acts as a trap to catch metallic grains. When the rock-strata is tilted up-stream, it makes a most effective catchment basin. A stratum of clay in a stream placer often collects and holds the concentrated metals, but makes their separation from the clay very difficult and expensive. It is evident that placer metals cannot be deposited in



Fig. 72. Gold Placer Deposit in Cavity of Upturned Bed. Rock Schists.

swiftly moving currents, but where eddies form or when a stream changes its channel the old bed is where workable deposits are usually found.

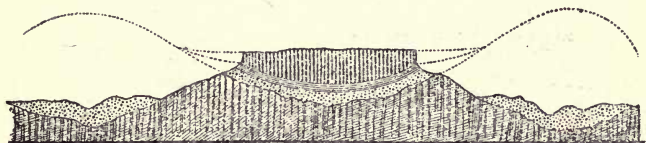
What Is the Origin of Ancient River Deposits?

30. These are found throughout California, often in the tops of the hills and mountains and sometimes capped by volcanic rocks from Tertiary eruptions. The presence of organic matter in the form of driftwood in such deposits is positive proof that they were ancient river channels, which have either since been pushed up or the adjacent country has

sunken. Fig. 48 shows an Ancient River Placer. The dotted line represents the original contour of the country, the basalt capping is assumed to have been formed by the flow of molten lava which diverted the river course elsewhere. Subsequent earth movements uplifted the beds, or depressions were formed on each side, leaving the Ancient River Deposits high and dry.

Sometimes an Ancient River Bed is depressed and covered up hundreds of feet by sedimentary or eruptive matter, making it necessary to sink shafts or drive tunnels to work such placers, as in lode mining.

Fig. 48



—ANCIENT GOLD-BEARING RIVER BEDS, TABLE MOUNTAIN, CALIFORNIA.

How Are Beach Placers Formed?

31. *Beach Placers* are found along the Pacific Coast of North America, the most noted being at Nome, Alaska, where the upturned strata of slate and schist carry gold-bearing veinlets, while the dikes, or cross-veins, act as dams or "pot-holes" to catch the gold. Fig. 49 shows a section of Nome Beach Deposits. The source of this gold is inland and not seaward. It was washed down by floods or glaciers, while subsequent earth movements possibly brought the gold in contact with the ocean tidal waves, to concentrate it into Beach Placers.

In these Beach Placers the gold is concentrated by the waves. The incoming tidal waves are counteracted by con-

tact with the shore-line, but the undertow of the receding tidal waves, assisted by gravity, carry the lighter particles seaward. This leaves the heavier particles concentrated behind into placer beds, which are often of remarkable richness.

What Is the Origin of Nuggets in Placers?

32. The origin of gold nuggets found in placers has long been somewhat of a mystery, and inasmuch as this question has an important bearing on placer mining, it deserves some consideration here.

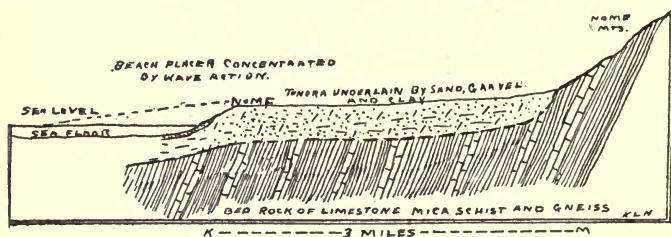


Fig. 49. Section Representing Nome, Alaska Beach Placers.

So far as the origin of fine grain and flake placer gold is concerned, the problem is quite simple. Gold is obtained from "free milling" ores and from gulches below such mines by panning, as from placer beds, which is convincing evidence that the origin of such placer gold is traceable to the eroded mineralized veins at higher levels. However, the existence of coarse grains of gold and nuggets in placers, often weighing from an ounce to several pounds, is not so easily explained. It is contended that such nuggets result from the decomposition of gold-bearing quartz. The silicious matter being more soluble than the gold content it disintegrates, leaving a

skeleton, or honey-combed structure. This contains tiny wires of metal, which moving rocks crush, and the malleable gold is consolidated into the form of nuggets. The fact that coarse placer gold often has little particles of quartz adhering to it seems to confirm this old theory. Still this explanation is not altogether satisfactory, and some recent writers have raised serious objections to this view. They point out that there is a directly opposite tendency in alluvial gold being ground into fine flakes and powder in moving from the heights to the basins below. It is also pointed out that gold in lodes is alloyed with silver ranging from 5 to 35 per cent, while the gold in placers is often almost chemically pure. Those who hold to the old theory, endeavor to explain that silver, being more soluble than gold, is dissolved out by acids and alkalies in water and the atmosphere, leaving the gold in the refined state. Laboratory experiments, however, do not bear out this assumption, as silver is very difficult to part from an alloy with gold, except when in finely divided particles.

The existence of large gold crystals within placers cannot be satisfactorily explained, except that they were crystallized within the placer beds themselves. We have seen that crystals are formed by two processes,—*fusion* and *solution*. If we assume such crystals were formed within lodes, their crystal form would surely be destroyed by erosion and corrosion in traveling from such decomposed vein outcrop to placer beds often many miles distant.

These recent writers contend that Gold Nuggets and crystals are formed within the placer beds by a sort of mineral growth. The gold is dissolved by combined action of alkalies and acids, and the metal burden being precipitated by natural reagents to form metallic gold around a nucleus.

This continued growth by accretion, or addition of precipitated gold, is believed to form the crystals and nuggets found in placers today. If it is admitted that gold is rendered soluble by the natural reagents in surface waters, it is reasonable to conclude that the origin of placer nuggets and gold crystals is within the placers themselves and that the metallic elements are concentrated from vast areas.

Coal Measures—What Are They and How Formed?

33. Coal is not a true mineral because it has a variable composition, but inasmuch as it belongs to the mineral kingdom it may very properly be classed as a mineral deposit.

Coal Measures occur in stratified beds and differ from other mineral deposits in origin. These have been formed from vegetable matter like mosses, lichens, shrubs and even whole primitive forests which have been submerged, in the processes of the ages, beneath the seas and covered with sedimentary rocks at varying depths. Coal is usually found in a sandstone formation with shale or slate for roof and floor, which are probably impurities driven out of the organic matter by pressure from above and baked by the earth's heat. Coal measures usually lie horizontal, but earth movements have often tilted up the beds at different angles. Instances are found in the Rocky Mountain region where the intrusion of an igneous dike has changed soft coal into anthracite. (See Carboniferous Age.)

Petroleum—What Is It and How Formed?

34. *Petroleum* varies somewhat in composition, like coal. The word literally means "rock oil" and the name "Coal oil" that was first applied to Petroleum is a misnomer, as it is not a product of coal, although often closely associated with it. The origin of Petroleum and natural gas has

puzzled the geologist and chemist from the date of their discovery. Chemists have been able to extract Petroleum from coal and also from limestone, and in some countries shale is ground up and the oil extracted on a commercial scale. A product closely resembling petroleum has been extracted from decomposing animal bodies by distillation. These facts point clearly to the source of Petroleum as a product of organic matter, both animal and vegetable, and on this scientists are now fairly well agreed. The processes by which Petroleum is produced in nature's vast underground laboratory are superior to anything known to man and have been in operation throughout vast ages.

The highest quality of Petroleum is found at considerable depth in the Devonian rocks, but it occurs in greater abundance in the rocks of the Carboniferous Age. As these were known to be ages of rank vegetation and abundant animal life, we have additional proofs of organic origin of Petroleum. The heavy California Oils occur in the Tertiary Rocks, just as low grade coals occur in the more recent formations.

The great oil bearing strata within the earth are always in regular beds of slate and cavernous limestones. The fine grained slates act as a roof to catch and hold the oil and gases generated below.

Fig. 50 shows a section of a California Oil Field, the oil stratum lying between shale strata, which follow the foliation of the enclosing rocks.

The *Anticlines* are shown at A and B. At C is shown the *Sincline*, the great natural reservoir for oil and wells drilled at such points usually prove the most productive.

At the extreme left is shown the outcrop of oil sand. Inexperienced oil miners often put down wells where oil appears on the surface, and the result is usually a "dry hole."

Petroleum is lighter than water, hence it rises and collects under the saddles, or anticlines, while the surplus water leaks out through fissures under the troughs or synclines, and in this way the oil is purified. In a few California oil fields the rock enclosing the oil strata have been pushed up and formed into basins similar to Ancient Placer Beds shown in Fig. 31 and Fig. 51.

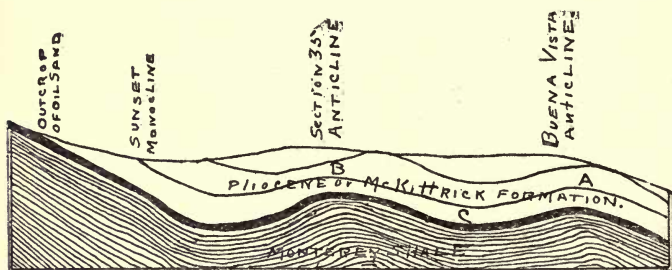


Fig. 50. Ideal Section Showing California Oil Field.

Unstratified Deposits

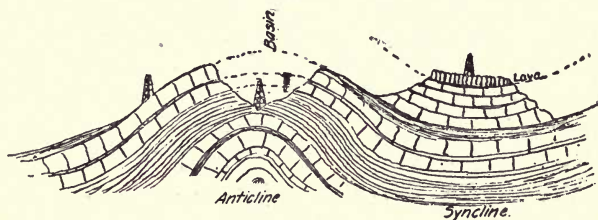
35. Before taking up the subject of Ore Deposits, it will be well to thoroughly understand the difference between a mineral and an ore, as well as the distinction between ore in a vein, and the vein itself.

What Constitutes An Ore?

An ore is defined to be any mineral, or aggregation of minerals from which a metal may be recovered at a profit over and above the cost of extraction. From this it is seen that the element of *profit* determines what is really ore.

An ore of pure minerals is unusual. It is possible for one to have a vein in which pure mineralogical specimens occasionally occur and yet not have an ore, on account of such minerals occurring in small pockets. Likewise a vein carrying a certain percent of metal in one section may be an ore, and in another section an equal proportion of the same minerals may not be an ore at all, owing to unfavorable conditions making the cost of recovering greater than the value of the metals extracted. For example, Pyrrhotite containing two per cent copper, if so situated that it can be economically mined and reduced, would constitute an ore, while the same

Fig. 51.



ANTICLINAL AND SYNCLINAL FOLDS.

percentage of metal in pyrrhotite, remote from railroad and smelter, or with unfavorable conditions for mining and extracting, would be consigned to the "waste dump."

Minerals formerly not considered ores on account of expensive methods are today, with improved processes and scientific treatment, valuable ores. The mineral Bauxite is now a valuable ore of Aluminum, but a century ago Aluminum metal was unknown, hence Bauxite was simply "rock." So also what we regard as common clay today, with improved scientific methods of the future, may become a valuable Aluminum ore.

36. *High Grade* is a term used to denote a high percentage of metal, depending somewhat on the metal content. When only a small percentage of metal is present, or low values, it is said to be *lean* or *low grade*.

An ore containing one per cent gold would be extremely rich, and hence properly named *high grade*, but one per cent copper, or lead, would be *low grade*, or no grade at all, even with the most modern methods in mining and extracting.

Twenty-five years ago iron ores of Lake Superior region carrying less than 60% were considered "low grade," but with modern methods ores carrying 40% iron are now considered valuable. In ore of the "precious metals," the gangue minerals—like iron, lime and silica, constitute the body of an ore, and the precious metals are usually present only in finely divided particles. So in order to determine the class of an ore, a general average must be taken of that portion of the vein material that must be removed in ordinary mining. Sometimes it is necessary to take average samples clear across from wall to wall in order to estimate the ton value of an ore body. Failure to observe this rule is responsible for more mistakes and failures in mining than any other cause. Another common error of the inexperienced is to conclude that every part of a ledge is equally good, or barren. Such mistakes arise from the belief that the vein is mineralized when formed, whereas ore occurs in "shoots," which in appearance do not differ from the "lean" or barren portion of the vein. (See Ore Shoots, Par. 46).

What Physical Conditions Influence Ore Deposits?

37. Ore being an aggregation of minerals collected from the great earth mass, it must be apparent that certain physical conditions favor the concentration of metallic particles to form ore deposits. These conditions are somewhat varied, but the following exercise the greatest influence, viz:

- (1) Dikes,
- (2) Faults,
- (3) Wall Rocks.

(1) *Dikes* of igneous rocks like porphyry, diorite, etc., are seldom mineralized and therefore unimportant in themselves. But when they occur in contact with or adjacent to regular veins they produce the morphological changes highly favorable to vein mineralization.

(2) *Faults* produced by earth movements may show themselves in sharp cuts extending great distances, or they may occur as a mass of fractured material. Regions subject to earthquakes are most extensively faulted, and similarly such regions contain the most valuable deposits of the precious metals. The open porous condition resulting from faulting permit the metallic vapors and mineral solutions to enter such cavities and deposit their metallic matter.

(3) *Wall Rock*, often affects both the vein and the filling. A tough enclosing rock may narrow a vein to a mere seam, and a soft wall rock may permit the vein to widen out. Soluble rocks like limestone and dolomite may give up some of their substances, and have them replaced by mineral solutions circulating through the vein fissures. Vein matter that is compact and continuous in one rock, passing into another strata, may split up into stringers so as to prove unprofitable.

Veins—What Are They?

38. *Veins* are faults or fissures in rock strata filled with mineral matter. A vein is made up of three parts, viz:

(1) The *open fissure*, which may be clean-cut, or simply a shattered zone.

(2) The *gangue*, or more or less valueless material, constituting the filling.

(3) The *Ore*, which only occurs in places within the vein.

Veins vary in width from an inch to many feet and from a few hundred feet to many miles in length. A vein differs from a Bed (See Par. 24) in that veins are unstratified and were formed after the rock strata had hardened, so as to permit faulting and fissuring.

Veins differ from Dikes in that they are filled in successive stages—a sort of mineral growth—while Dikes are fissures filled with igneous rocks at a single eruption, and therefore of uniform structure. Dikes have their walls burned and baked by the heat from the eruptive matter. Veins are softer, easily fractured and oxidize rapidly, while Dikes are hard and decompose more slowly than the enclosing rocks. (See Fig. 52.)

39. A *Lode* is a more general term than Vein, and this is used to designate any fissure or mineralized country rock. As used in the U. S. Mining Laws, the term *Lode* applies to any mineralized Zone or Belt lying within boundaries clearly separated from neighboring rocks.

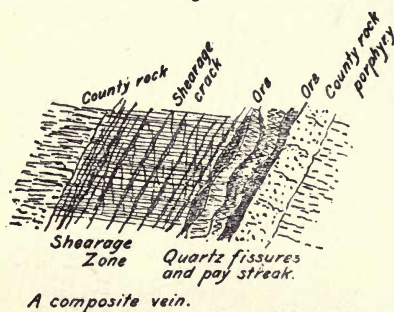
40. A *Mineral Belt* is a section of country through which run a series of parallel veins having a common origin.

The "Mother Lode" in California lies in a *Mineral Belt* about fifty miles wide and nearly one hundred miles in length.

41. *Country Rock* is a term used to designate the rock which encloses a vein or bed. (See Fig. 52.) When the vein varies from the vertical or horizontal, the wall rock forming the roof is called the *Hanging Wall*, and that forming the floor is called the *Foot Wall*.

42. *Strike* is the extension of a vein or lode in a horizontal line. In other words, it is the course or trend of the

Fig. 52



vein, usually conforming to or running parallel with the course of the hills or mountains.

43. *Dip* is the term used to designate the angle a vein makes with the horizon in its downward course. Fig. 53 shows the methods of measuring Dip. From the horizontal to the vertical is 90 degrees, making what is called a Quadrant, or quarter circle. A vein forming a one-third angle from the horizontal would be 30 degrees Dip; one-half pitch would be 45 degrees Dip, and so on as shown in the scale.

Dip is sometimes stated in per cent measured from the vertical line. Thus one-fourth incline from the vertical would be termed 25% Dip, one-half 50% Dip, etc., as shown in Fig. 53.

The Outcrop of a vein is what appears on the surface. Sometimes a vein is harder than the wall rocks and will stand out boldly, or some portion of the vein may be hard and other parts soft, due to difference in fracturing and cross fissuring. When a vein contains soft and soluble

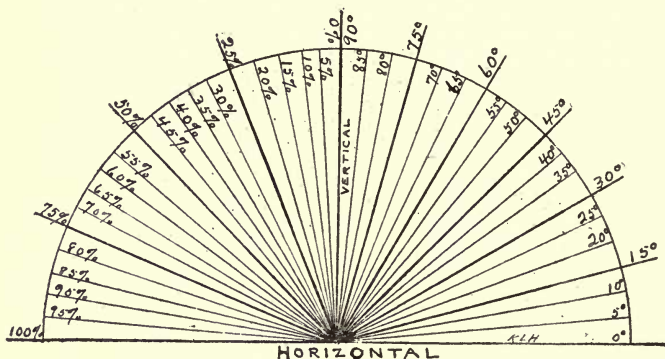


Fig. 53. Illustrating Dip Veins.

matter it may be worn away so there is no outcrop at all, and in that case it is said to be a *blind lead*. Often such decomposed veins may be traced by stains imparted to the country rock along the "strike." Oxide iron gives a yellowish or brownish stain, but copper carbonates impart a greenish or bluish stain. This decomposed stained ledge matter is called by miners a "Gossan" or "blossom," and often contains free gold, or the oxides and carbonates of lead, copper, etc.

45. A *Horse* is a miner's term to designate fragments

of wall rock included within vein matter. The country rock may become fractured so that the vein in the process of formation enclosed a fragment of wall rock which became detached, or a rock fragment may be forced into the vein after it is formed. In either case the vein is split into one or more parts. Fig. 54 shows "horses" as they occur in a Colorado mine; the light colored portion represents the true



Fig. 54. Horses in Fissure Vein, San Juan Region, Colorado.

vein matter, and the enclosed matter constitutes the "horses." It is not unusual for a vein to branch and come to the surface in a system of parallel veins, all in rocks of a similar age, but where a vein splits in its downward course to form "horses," as shown in the lower portion of the figure, it is an unfavorable indication and is often a slur on the mine or prospect.

What Are Ore Shoots?

46. Veins are often perfect in form and structure, but imperfect in mineralization, or they may be absolutely barren. When ore occurs in a vein it is usually irregular in shape and extent. In ideal veins, and in the best mines, ore is found in certain sections of veins, while other portions of the same vein may be imperfectly mineralized, or entirely valueless. Those portions or sections of a vein carrying "Pay Ore" are called *ore shoots* (or chutes), also called *Pipes of Ore*, from their pipe-like shape. A common name amongst miners is *Ore Chimney*, which name applied by those who believe that all ore bodies are formed within veins by metallic vapors arising from the earth's interior through open vents similar to the movement of smoke through a house chimney. While it is true that there are many ore bodies to which the name "chimney" is appropriate, yet for ore bodies formed by the deposition of metallic elements from circulating solutions the name *Shoot* is almost universally used by scientists today.

The origin of Ore Shoots is not fully understood, although we know they exist, and their characteristics are also well known, but the causes are not fully determined. However, the fact that they always occur in the more open and porous portions of veins makes it obvious that such cavities and weak spots, due to earth movements, permit the metallic vapors and mineral solutions to enter and deposit their metallic burden to form ore deposits. It is a universal natural law that "all forces move along the line of least resistance," and the forces that operate in the formation of ore deposits form no exception to the general rule.

Fig. No. 55 shows typical Ore Shoots, illustrating the occurrence of ore within veins, with Ore Shoots and "poor ground," alternating along the course of the ledge. In a system of veins having a common origin, ore is found opposite ore, and barren matter opposite barren matter. In many mining districts mine shafts, or shoots in parallel veins, form a line at right angles to the strike of the vein system, so that

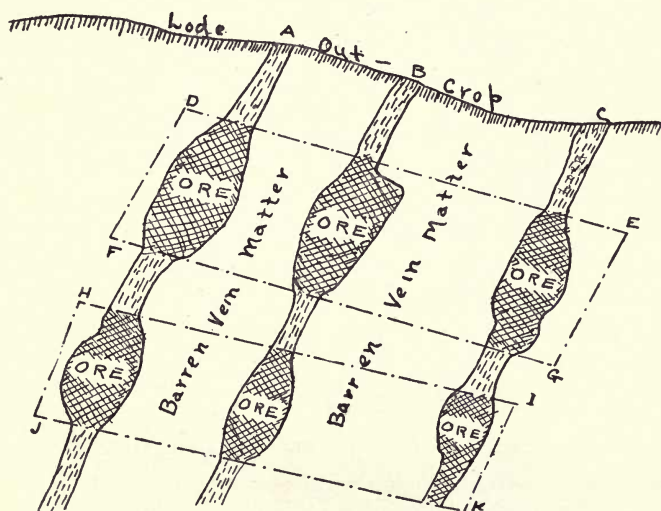


Fig. 55. Cross Section of Vein Showing Occurance of Ore Shoots.

one unfamiliar with the district often concludes the veins run contrary to the real course.

In a vertical section of a vein the Shoots likewise are arranged ore opposite ore. (See Fig. 56.)

The largest and richest ore shoots are usually found near the middle of the vein system, but other shoots often occur at regular intervals along the course of the vein, sometimes

with 25 to 50 feet barren ground between, and at other times 500 to 1000 feet between shoots.

Fig. No. 57 shows one vein wall removed, the shaded portions representing pay ore and the light portions the poor ground. These shoots are ideal, and such perfectly defined sections are unusual. It must not be inferred that the ore differs in form or structure from the barren ground, except that the ore is more fractured and contains all the values.

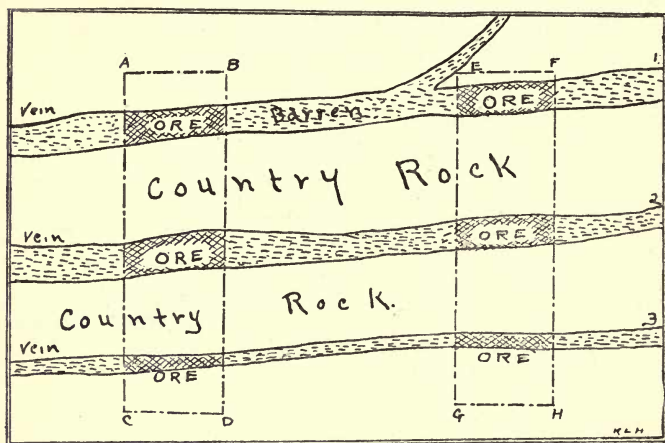


Fig. 56. Horizontal Section Showing Ore Shoots in Parallel Veins.

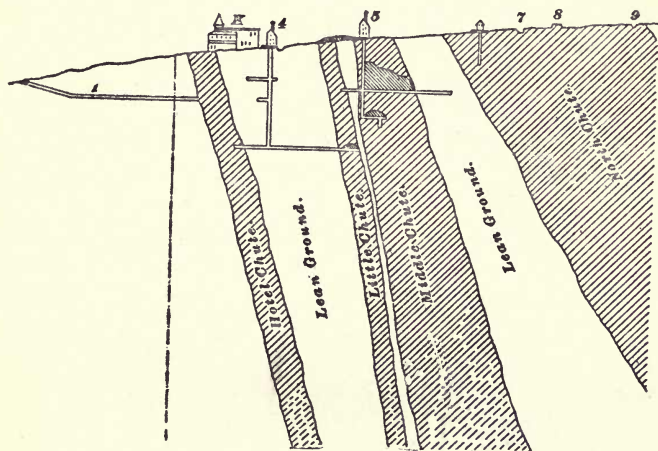
Shoots go from the surface downward to various depths. As a rule they are deeper than they are long. When a Shoot stops at a shallow depth, it is called a *Pocket*. Some ore bodies are a succession of pockets, connected by only a narrow strip of ore, or at times by only a "mud seam."

Ore shoots are not always vertical, but may pitch to the right or to the left. They are, however, generally uniform in any vein or mineral belt in their general characteristics.

Veins have been found that contain ore their full length, and the "shoot" only stops because the vein "pinches out," but this is unusual.

It is a common error to suppose that a mining claim on the same vein as a noted ore producer will become equally valuable, but those familiar with the occurrence of ore shoots never commit such a blunder. Many a valuable prospect has been abandoned because a shaft in its downward course passed out of an ore shoot into barren ground. Since ore

Fig. 57



—ORE CHUTES AT GOLD COIN, VICTOR, COLORADO.

bodies vary so much, it becomes necessary for the mining man to make a close study of his vein to avoid mistakes and useless expense in mining operations.

Do Veins Grow Richer With Depth?

47. In the early history of lode mining in California, it was thought that veins decreased in value with depth.

This belief was due largely to the fact that "free gold" values became less with depth. Many good mines were abandoned, until science devised methods of extracting the

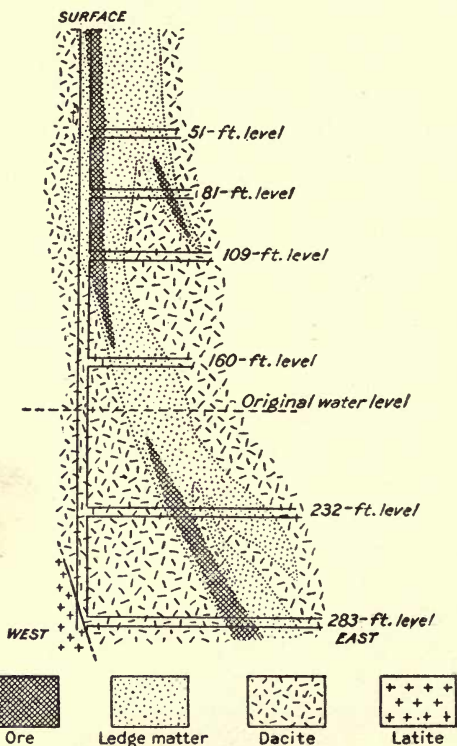


Fig. 58. Section of a Goldfield, Nevada, Mine.

values from base ores. In recent years a popular idea has prevailed amongst fairly well informed mining men that mines grow richer with depth; this may or may not be the case, owing to the mining district. The experience in a

developed mine is usually the only safe guide for other mines in the same mineral belt. Those who believe that all veins are filled and mineralized by eruptive metallic matter from the earth's interior conclude that as you approach "nature's Melting Pot" the quantity of metal should increase. Others who think fissures are filled from above, by washing into them solid metallic elements, reason that a vein must grow richer with depth because "the heaviest always goes to the bottom." The accepted modern theories of the "Origin of Ore Deposits" heretofore named compel us to discard these erroneous notions.

Deep mining operations in various parts of the world have demonstrated that rich ore bodies often occur at the junction of different rock strata (see Fig. 62), and it is equally well proven that rich ore bodies are often found at or near the permanent water level. It is the rule in mining to find between the surface and the water level a section or "Zone of Impoverishment" (lean ores) followed by a deeper zone of "high grade" at the water level, the latter being known as "Secondary Enrichment," due to the leaching of the ore above and the precipitation of the metallic contents below. Sometimes this zone of "high grade" is exclusively of oxides above and sulphides below the water level, while as mine workings reach the old primary ore deposits the values grow less and often disappear entirely.

However, this rule, like all others, is subject to exceptions. Fig. No. 58 represents a section of a mine at Goldfield, Nevada. It will be noticed that at the "Original Water Level," the shaded portion of the ledge matter representing ore, tapers out to a point and "quits" at the 160 foot level, only to reappear below the old water level. This singular occurrence is common in the principal mines of that particu-

lar mining district. It will also be noticed that the vein and ore is almost vertical above water level, and below this the dip is from the vertical towards the east, which is also contrary to the general rules pertaining to dip in veins. The ore deposits in the entire Goldfield district are abnormal, and have proven a puzzle to the geologist and mining engineer.

Facts are always better than theories, and to determine whether mines generally grow richer with depth several eminent authorities have compiled statistics of the principal mines of the world, which show that in the majority of cases mines *do not* increase in richness with depth, but on the contrary decrease in value, if not in the size of the vein itself, at from 1000 to 2000 feet depth, although there are some remarkable exceptions to this rule. Usually the most profitable period in a mine is the first 1000 feet depth; below this, if values do not decrease, the extra cost of hoisting ore, mine drainage and treating the more refractory ores nearly always makes the net returns less. A notable exception to this rule is in copper veins, many of which are unprofitable until the sulphides are reached.

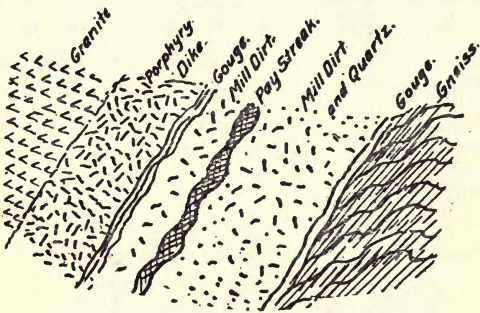
HOW VEINS ARE CLASSIFIED

Fissure Veins—What Are They?

48. A *Fissure* is a crack in the earth's crust, caused by contraction due to cooling, which is enlarged by the eruptive forces within the earth. A *Fissure Vein* is a fissure filled by mineralized matter. Fig. 59 shows an ideal section of a Fissure Vein. At the left is seen a porphyry dike which frequently accompanies a mineralized Fissure Vein, and such an occurrence is always welcome. Adjoining the porphyry

on one side, and also next the gneiss foot-wall, is seen the *Gouge* or *selvage*, which is usually a form of clay or talc resulting from decomposition of feldspar. Sometimes "gouge" occurs in the middle of a vein, when it has been reopened by earth movements. Often this gouge matter contains metallic minerals, and is characteristic of True Fissure Veins, usually serving as a guide in following a vein that is somewhat broken up; when a vein is narrowed down to a thin seam, the gouge matter is continuous.

Fig. 59



—IDEAL SECTION OF A FISSURE VEIN.

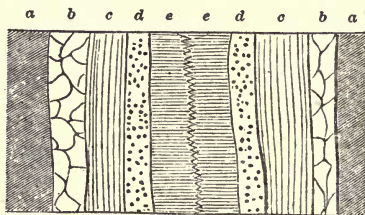
The "Mill dirt and quartz" constitute the *Gangue*, usually forming "low grade ore." The "Pay-Streak" is the "high-grade" ore. As the gangue must usually be removed along with the Pay-Streak, the value of the ore in such a vein is represented by an average taken across from wall to wall.

A True Fissure Vein has polished walls, which are more or less "striated" (scratched) by friction, to which they are subjected by earth movements after the vein was formed, these smooth wall surfaces being known as "Slickensides."

A fissure vein has both hanging and foot walls of the same kind of rock, although in passing through sedimentary strata the divided rock strata may be somewhat Faulted. Fissure veins in crystalline rocks, like granite, have both walls granite, although the character of the granite may be somewhat different. A fissure vein may in some part of its course follow the dip of the stratified rock, and may thus be mistaken for a Bed, but if with depth the vein cuts across a strata it may be pronounced *True Fissure Vein*.

The normal position of a Fissure Vein is an upright one, but a slipping of the hanging wall rocks may throw the vein into a horizontal position and produce what is called a *Blanket Fissure Vein*, which is sometimes mistaken for a "bedded deposit."

Fig. 60



—Section of a Fissure Vein, showing banded structure.
 a a, country rock; b b, calc spar; c c, galena; d d, heavy spar—sulphate of baryta; e e, comby quartz.

Fissure Veins often have a "Banded" or "Ribbon" structure as shown in Fig. 60. In this type of veins, which is not uncommon, the ore is arranged in alternate bands or layers in accordance with the successive growth of the vein filling. In the Figure, b, b—is calc spar, which may carry lead ore; c, c—may carry manganese; d, d—copper, while the center bands e, e, may consist of a mixture of all the ores named. Sometimes seams of talc or gouge occur between the differ-

ent bands as well as in the center streak. This banded structure is peculiar to Fissure Veins, but all Fissure Veins are not banded.

The Theory of Origin of Banded Veins is somewhat as follows:

First there is a crack, or fault, in the rocks, which opened to receive metallic solutions which formed the center bands *e, e*. Earth movements cause a reopening of the fissure, and the solutions enter along the walls to form bands *d, d*; refissuring causes the walls to further spread and new solutions enter to form *e, e*; a repetition of the process results in the bands *b, b*, leaving the walls *d, d*, at the close of the epochs widely separated, which in the original fault were contiguous.

In the early history of mining ore bodies were supposed to be confined to fissure veins in granitic rocks of the Archian age, and while fissure veins are of greater length and more continuous in depth, yet later mining experience has shown other forms of veins to be equally important sources of ore bodies.

Fig. 61 shows an ideal section. illustrating fissure veins and their general characteristics. At *A* is seen a fissure vein in Rhyolite, both walls the same igneous rock. *B* and *C* are True Fissure Veins proceeding out of granite, a crystalline rock, and cutting strata of slate, limestone and sandstone, all sedimentary rocks. At *D* is seen a somewhat different type of vein, the Rhyolite, an igneous rock forms one wall, the other wall being formed by both sedimentary and crystalline rocks forming what is called a Contact Fissure.

How May the Age of Fissure Veins Be Determined?

49. There are several kinds of Fissure Veins as well as fissures of various age, some are barren and others valuable, so it becomes every mining man to be able to tell the relative age and importance of veins when they are found to intersect one another.

As a general rule it may be said that the older veins are the best mineralized, and the younger veins of least import-

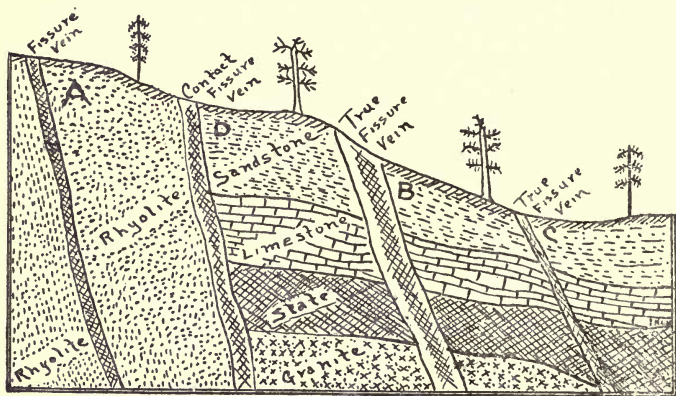


Fig. 51. Ideal Geological Section, Illustrating Fissure Veins.

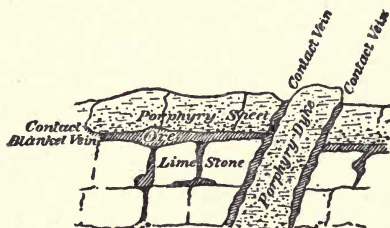
ance. The older fissures usually follow the trend of the hills or mountains while cross fissures are usually younger and of less importance as a source of metals. When one fissure meets another at something like a right angle, the older vein is always faulted by the younger. Fissures having the same dip usually have the same origin and age, while as a rule those having opposite dip belong to different periods.

Contact Veins—What Are They?

50. A *Contact* in mining means the meeting of two different formations, and a *Contact Vein* is the filled cavity that occurs along the plane of contact of dissimilar rocks. Contact Veins usually occur at the junction of eruptive, or crystalline rocks, with sedimentary or stratified rocks, but they are sometimes found between unlike stratified rocks, as at the junction of shale and sandstone with limestone, in which case they are likely to be mistaken for *bedded deposits*.

Contact Veins are formed by the intrusion of igneous rocks into sedimentary rock strata. Fig. No 62 shows con-

Fig. 62



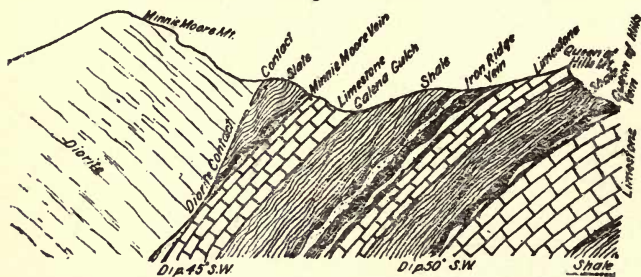
ILLUSTRATING CONTACT VEINS.

tact veins occurring between limestone and porphyry, the latter having been forced up through a fissure, and while in a plastic state spread out sheet-like at the surface, between which and the limestone beneath a Blanket Contact Vein was formed. The soft porous limestone disintegrates rapidly forming cavities in which the metallic solutions deposit their solid matter to form ore.

The uplifting of mountains through giant fissures in sedimentary rocks forms contacts of great extent. The sedimentary rocks adjacent are usually tipped up, and a series

of contact veins may result as shown in Fig. 63. Here the diorite mountain at the left was apparently intruded after the sedimentary rocks had been formed. The main contact shown at the left is between slate and diorite at the surface, and with depth the slate disappears, leaving a contact between limestone and diorite, along which was formed the principal ore deposit of the district. The other contact veins shown in the Figure partake of the nature of *beds* which have subsequently become mineralized.

Fig. 63



—ORE DEPOSITS, MINNIE MOORE MINE, IDAHO.

Contact veins occur in California between granite and slate in a somewhat vertical position. In Colorado the ores of the Leadville District occur in "Blanket Contacts," of limestone and dolomite with quartzite and porphyry.

Contact veins are next in importance, as ore bearers, to fissure veins, and some regard them with greater favor than all other veins, although not so extensive in strike and depth as fissure veins.

A Contact Fissure Vein partakes of the nature of both contact and fissure veins. The walls are dissimilar, but one wall conforms with the foliation of the stratified rocks while

the other wall may be a crystalline rock, or composed of stratified rocks in the upper course with a faulted igneous rock below.

Fig. No. 64 is an ideal section, illustrating Contact Veins. At *B*—is a contact between Gneiss and Slate; *C*—is a contact between Slate and Limestone. At *D*—is shown a contact having both walls sedimentary rocks; at *G*—is seen a Blind Fissure Vein, and *E*—is a True Fissure Vein, both of which have been faulted.

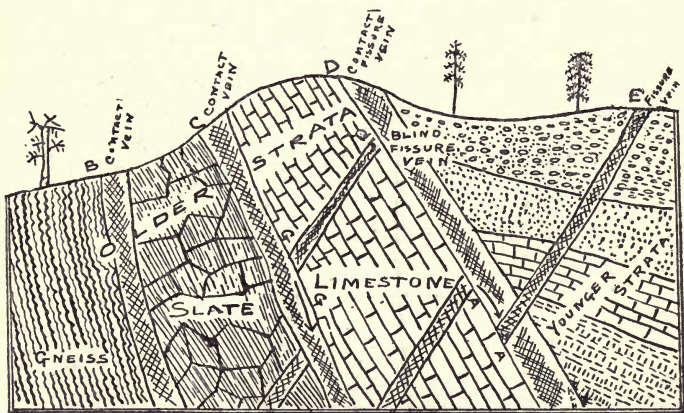


Fig. 64. Ideal Section Illustrating Contact Veins.

Gash Veins—What Are They?

51. *Gash Veins*, as the name indicates, are simply filled gashes or surface fissures. They usually taper to a point in their downward course and disappear. As a rule they are a most unsatisfactory type of veins, and when mineralized little dependence can be placed on them, although they often contain pay ores. Many lead deposits in the Mississippi Valley occur in typical Gash Veins, largely in limestone rocks, the

ore forming in bunches, at the intersection of different rock strata, where the metallic particles are concentrated, either from leached wall rocks or from circulating waters in fissures adjacent to such Gash Veins. An occasional Gash Vein is found in volcanic rocks as seen at *B* in Fig. 65. At *C* is seen a Contact Gash Vein between volcanic and sedimentary rocks; *D* and *E* are typical Gash Veins in stratified rocks, the True Fissure Vein at *F* shown by contrast, cutting across the stratification and continuing downward in undiminished size.

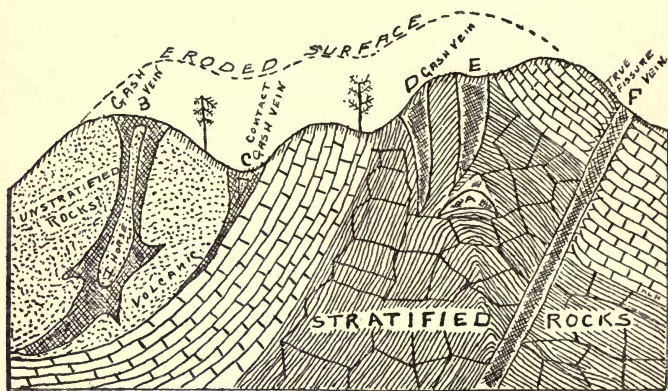


Fig. 65. Ideal Section Illustrating Gash Veins.

What Are Segregation Veins?

52. Segregation Veins conform to the foliation of the enclosing rocks, and the ore in such veins is usually arranged in lenses, or in the form of kidneys. They differ from contact and bedded veins in the irregularity of ore in structure of vein and in arrangement of the minerals within the vein. Segregation veins often have a banded structure like fissure veins, but differ from them in showing no evidence of fault-

ing, and in always following the folding and twisting of the wall rocks. Fig. 66 shows the most common occurrence of ore in segregation veins in crystalline and other rocks. The lead-silver mines in Idaho occur in rocks of slate and quartzite, the ore forms in pockets or large masses. Many low

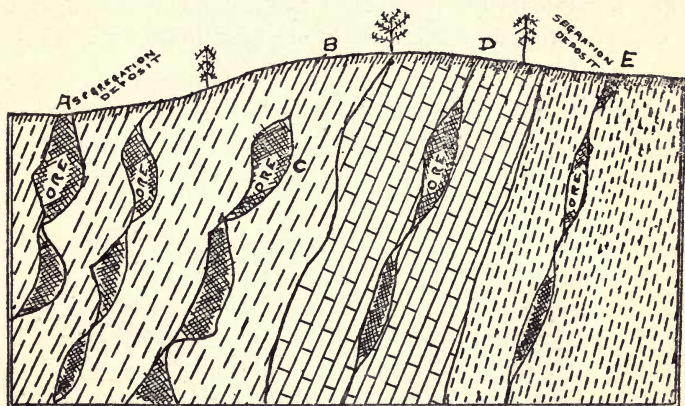


Fig. 66. Ideal Section, Illustrating Segregation Deposits.

grade mines in the Black Hills of South Dakota, occurring in schist, belong to this class. Segregation veins are not uncommon elsewhere, and are as well defined as Simple Fissure Veins, but more irregular in ore arrangement.

IRREGULAR ORE DEPOSITS

53. Irregular Deposits, as the name indicates, are of more complex origin and less uniform in occurrence. Such deposits have no regularly defined walls, nor fixed limits, hence it is difficult to estimate their extent or permanence. These are classed under three heads, as follows:

- (1) Chamber Deposits.
- (2) Impregnation and Stockwork.
- (3) Fahlbands.

What Are Chamber Deposits?

54. *Chamber Deposits* are cavities filled with ore, sometimes called "Cave Deposits," for the reason that it was believed caves were first formed and afterwards filled with ore. The origin of such deposits is not thoroughly understood, hence open to controversy. From the fact that Chamber Deposits usually occur in limestone or other soluble rocks, it is believed that cavities were first formed by the dissolving action of surface waters, and the metallic minerals were later deposited in such cavities from mineral solutions, circulating through fissures in the country rocks. Some authorities contend that the metallic substances in chamber deposits are derived from the country rocks by replacement (see Par. 19); that is, the mineral solutions after depositing their metallic content, took up an equal amount of soluble rock matter and deposited it at lower levels. This process of substitution, it is assumed, was continued through the ages, and resulted in the chamber deposits found throughout the world today. The weight of authority, however, inclines to the opinion that the ore in chambers was derived in a manner similar to that found in fissure veins, due to complex fissuring

and faulting, forming open conduits connecting with cavities in which the ore now occurs.

Fig. No. 67 shows a series of Ore Chambers in limestone and igneous rocks.

The presence of igneous dikes adjacent to ore chambers seems to confirm the view that the ore is derived from below, as in regular vein formation.

It is an admitted fact that chamber deposits are seldom found below the natural water level, which makes the future

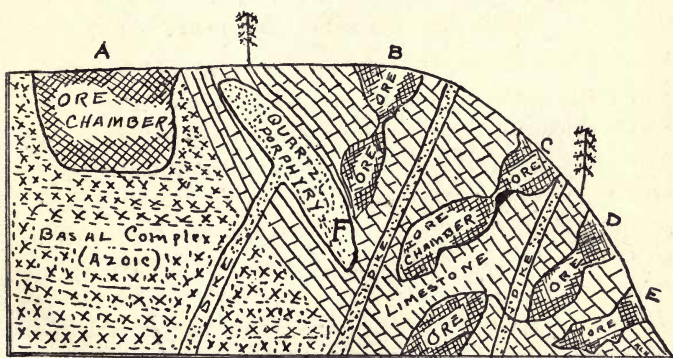


Fig. 67. Ideal Section Illustrating Chamber Deposits.

of such mines uncertain, while adjoining mines gain no prestige by virtue of their association, as in a regular vein formation. Several lead mines of the Mississippi Valley and most lead-silver mines of the Rocky Mountain and Pacific Coast regions belong to this class. The Jerome, Arizona, copper Chamber Deposits occur in Azoic rocks, as shown in A, Fig. 67, while the Bisbee District (Arizona) copper Chamber Deposits occur in limestone rocks; but whatever the formation such deposits are always associated with quartz

and porphyry. Chamber Deposits of gold and silver are rare, although these metals are frequently found associated in small quantities with copper and lead Chamber Deposits.

What Are Impregnation and Stockwork Deposits?

55. *Impregnation and Stockwork* are so similar in origin and occurrence that they may properly be classed under the same head, although several authors treat them as distinct types of deposits.

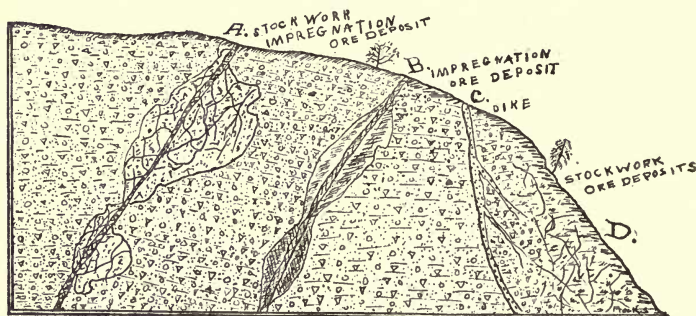


Fig. 68. Ideal Section Illustrating Segregation and Stockwork Deposits.

Impregnations are so closely allied to fissures that they are sometimes called Impregnation veins. They usually occur with narrow fissures in the more open and porous rocks, the more soluble elements like lime, feldspar, etc., are dissolved out, and the cavities left are filled by replacement or by a substitution of metallic elements from solutions for these dissolved out of the wall rocks. Where the vein material is very hard the wall rocks may become more highly mineralized than the vein itself. Fig. 68 illustrates Stockwork and Impregnation Deposits. At B is shown an Impregnation Ore Deposit, being a fissure with an arrangement of ore in the

vein as well as in enclosing rocks. The Ore Deposits in the Goldfield, Nevada, district, partake of the nature of impregnations, the veins occurring in volcanic rocks like andesite, rhyolite, etc., while the vein filling is a hard jasper quartz. Where earth movements have broken up the vein matter, ore shoots are confined entirely to the vein matter, but often the wall rocks are more highly mineralized than the vein itself, and the only way to tell ore from "waste" is by the presence or absence of metal values. At *A*, in Fig. 68, is shown a Stockwork similar to Impregnation, except that the mineralization extends farther out into the wall rocks and little veinlets are seen running here and there, characteristic of Stockwork. At *C* is seen Stockwork, unconnected with a vein, being simply a section of country rock filled with veinlets of ore, making the origin very uncertain, but the presence of dikes adjacent to such stockwork indicates the mineralization took place through the medium of the dikes.

Such deposits occur in different geological formations, usually in the more brittle primitive rocks, but they never continue below the oxide zone, while many do not extend more than 100 feet below the surface.

The origin of Stockwork is believed to be due to a sudden cooling of the hot crystalline rocks, by the intruding of surface waters, causing fractures and cavities into which mineral solutions entered to deposit their metallic burden.

Impregnation and Stockwork Deposits occur in many parts of the world, producing many ore deposits valuable enough to be profitably worked. In Idaho such deposits of gold, silver and lead occur in schist and quartzite. Many low grade mines in Colorado and the tin deposits of England and Germany occur in Impregnations and Stockworks.

What Are Fahlbands?

56. *Fahlband Deposits* are accumulations of metalliferous minerals in certain soft and porous rock strata, usually schists and shales. Fissures, cutting through rock, are found to bear ore when they intersect porous rock strata, or Fahl-

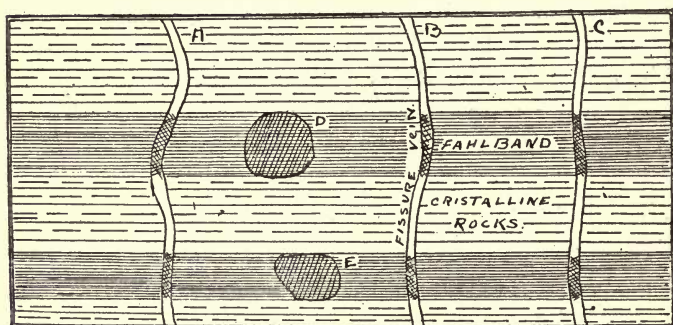


Fig. 70. Ideal Section Illustrating Fahlband Deposits.

bands, and in passing into a hard strata of crystalline rock become practically barren. This alternate arrangement of hard and soft rock strata is favorable to the production of Fahlband Deposits, which not only include the mineralized portion of the vein, but also the fahlband rocks cut by the fissures.

Fig. 69 shows a horizontal section of Fahlband Deposits. The shaded strata are the Fahlbands and the lighter colored strata represent the crystalline rocks. *A*, *B* and *C* are Fissures, cutting across the formations; *D* and *E* are ore bodies formed within the fahlbands, while the entire fahlbands are often mineralized so as to form low grade ores.

The origin of Fahlband Deposits is a matter of dispute. Some contend that the metallic substances are derived from

the country rocks by "replacement" according to that theory (See Par. 21). But the fact that Fahlband Deposits occur adjacent to fissure veins makes it appear more reasonable that their origin is due to the metallic solutions entering the porous rocks from the fissures, hence they do not differ materially in origin from the other classes of deposits previously described.

Fahlband Deposits occur in the Jura-Trias shales of California. The immense low grade ore bodies of South Dakota, averaging \$3.50 to \$4.00 per ton, are mainly Fahlband Deposits in schists. Ore bodies occurring in Fahlbands are usually lens-shaped and several hundred feet across. In Norway a Fahlband zone is known to be 100 miles long and 50 miles wide, being worked for the ores contained in narrow fissure veins.

What Are the Common Errors in Regard to Ore Deposits?

57. Many mistaken notions prevail in regard to mining in general and ore deposits in particular, and it will no doubt prove of interest, if not profit, to refer to some of these. They may be grouped into two classes:

- (1) Mistakes due to ignorance and inexperience, and
- (2) Mistakes due to experience with bad judgment.

(1) MISTAKES DUE TO IGNORANCE AND INEXPERIENCE

58. Mistakes due to these causes are natural and to be expected, but they may be prevented by mining knowledge and practical mining experience, so it may not be amiss to notice the most prominent.

Many hard headed business men, who have succeeded in commercial lines, assume that they can be equally successful

in mining without any knowledge whatever of the science of mining. Others regard mining as a mere matter of "Chance," but the mission of this book will have failed if any reader falls into such fatal errors.

Fig. 73



COMPOSITE VEIN CROESUS MINE, IDAHO.

An equally grievous error of the unlearned and inexperienced is to disregard all geological formations and adopt the slogan that "Gold is where you find it," and to assume that you are as apt to find a gold mine in digging a well or driving a water tunnel as anywhere else.

A common saying amongst the unlearned and inexperienced is that "One man can see as far into the ground as another;" in other words, that the novice in mining knows as much of what is below as the mining engineer. So far as the physical eye is concerned one man's sight may be as good as another's, but the scientific eye can penetrate solid rocks and often see more than the untrained eye can see after a shaft is sunk.

Many who are ignorant of vein formation and the principles underlying ore deposits, jump at the conclusion that a mining claim adjoining a rich mine will prove equally valuable. Such a thing does now and then happen, but it will not do to act on such a supposition.

(2) MISTAKES DUE TO EXPERIENCE WITH BAD JUDGMENT

59. It must not be thought that *experience* will always guard against errors. *Experience* is a good teacher, but many fail to learn with the best of teachers, and go on making the same mistakes over and over again. However wisdom and experience amalgamated make a safe guide and will prevent the errors which are all too common in mining operations.

A common error is for a miner to judge every mining section by his experience in a particular district, and it frequently happens that a prospector removing to a new country utterly fails because he expects to find rock formation and ore deposits like those at the old "strike." Old Comstock miners removing to new districts were wont to believe that no ore deposits of value could occur unless accompanied by porphyry-dikes, but many learned their error when it was too late. Many California miners in the "Contact" district today believe that no gold veins can be profitable unless they have a slate hanging wall and a granite foot-wall, because of their

experience in that particular district, but as a matter of fact such a combination is rare in the world's best mines.

Likewise Granite was once considered unfavorable for precious metal ores, because veins in the Mother Lode region, occurring in granite, had proved unprofitable, but veins in granite in other portions of California, in Nevada, Idaho and Utah, have proven this idea to be wholly false.

In early days, Limestone was "passed up" by miners, but Leadville, Colorado, and Eureka, Nevada, deposits of silver-lead have proven that limestones may not be wholly disregarded in mining operations.

As a rule sedimentary rocks are unfavorable for ore deposits, but the Silver Reef Mines of Utah, occurring in sandstone, have proven a notable exception.

Early California miners believed rich gold ores existed only near the surface, and frequently abandoned their mines at a depth of a few hundred feet, but it remained for later generations to upset this prejudice by sinking to a depth of nearly a mile in several mines all in profitable ore.

Present day miners often make the mistake of going to the other extreme in assuming that all mines grow richer and veins larger with depth. It is quite generally true that copper mines do increase in value with depth and few miners expect great copper values until the sulphide ores are reached, but it will not do to jump at the conclusion that all mines grow richer with depth, for, as it has been previously shown (Par. 47), the reverse is true in a majority of the world's mines.

From these observations, we should understand that while the character of rock formation is a good "indicator," it will not do to jump at the conclusion that ore deposits are confined entirely to any one class of veins or rock formation, nor that

rich ores are confined to surface workings, nor found only at great depths. The practical mining man should be conservative. Form opinions he must, as all will who use their reasoning powers, but definite conclusions and fixed opinions should not be formed except on strong evidence and corroborative proofs. He should rather regard the old maxim, "Prove all things and hold fast to that which is true."

General Principles Governing Ore Deposits

60. From what has previously been stated it must be evident that no hard and fast set of rules can be laid down in regard to ore deposits.

Certain physical and chemical agencies appear to have been more active in certain districts than in others, and this has produced quite a variety of ore deposits, but certain fundamental principles underly them all, so that ore deposits are much the same the world over.

The mining industry has now reached such a stage that every important mine and district throughout the world has been observed and a record made of their characteristics, so it is now possible to formulate rules based upon actual experience, and these may be stated as follows:

(1) VEIN RULES.

61. (a) Veins that follow the trend of mountain ranges are generally well defined and the most productive.

(b) Veins which cut across mountains or hills are generally of a later geologic age and imperfectly mineralized.

(c) When a vein is faulted by another vein, the faulted vein is the older, and usually the most productive.

(d) Parallel veins of certain known strike and dip have

the same origin and are usually better mineralized than those that vary a few degrees from the common course.

(e) Veins of hard material are usually "lean" and sometimes absolutely barren, while the softer and more porous sections of all veins are the most favorable for ore deposits.

(2) COUNTRY ROCK RULES.

62. (a) Crystalline rocks are the most favorable for ore deposits, but contacts of igneous with sedimentary rocks are also very favorable for rich ores.

(b) Intrusive volcanic rocks that tip up formations nearly vertical are most frequently associated with well mineralized veins.

(c) Porphyry rocks in or adjacent to veins constitute a favorable indication for valuable ore deposits.

(d) Quartz-porphyrries are generally associated with extensive copper deposits.

(e) The nearer a vein approaches a vertical position, especially above the water level, the richer the ore is likely to be.

(3) ORE SHOOT RULES.

63. (a) Ore generally arranges itself into clusters or bunches, to conform with the dip and cleavage of the enclosing walls.

(b) Ore bodies in a parallel vein system generally occur in cross zones, ore opposite ore and barren ground opposite barren ground.

(c) Ore is usually richer in the narrower and pinched portions of a vein, and lower grade in the wider portions.

(d) High grade ore usually occurs at the intersection of a dike, or another vein, with a mineralized vein.

(e) Enlarged ore bodies generally occur in a fissure vein where it passes from one class of rock into another.

(f) Gold ores as a rule are more profitable in the oxide zone and frequently decrease in ton value below the water level.

(g) Gold ores with values largely in pyrites seldom yield value after pyrites change to marcasite, or white iron.

(h) Ore enrichment usually occurs when a vein changes in strike or dip, but this often gives way to lean ore below the point of enrichment.

(4) MISCELLANEOUS RULES.

64. (a) A heavy iron capping (*Hat or Gossan*) at the vein outcrop, indicates extensive sulphide ore bodies at depth.

(b) Oxides and carbonates of copper and lead, resulting from the decomposition of sulphides of those minerals, never continue below the natural water level, where they change to sulphides.

(c) Local enrichments of oxide and carbonate minerals result from leaching of ore above, whose metallic elements are precipitated below.

(d) Deposits of Mercury ore (*Cinnabar*) rarely occur in paying quantities except in porous serpentine, or sandstone rocks, which have been faulted by intrusions of igneous rocks.

(e) Intrusions of porphyry or quartz-porphyry when occurring in or near a vein are favorable indications of valuable ore deposits.

(5) GENERAL OBSERVATIONS.

65. All rules, whether pertaining to mining or otherwise, have their exceptions. Some rules that fit perfectly to conditions in one district may be only partially applicable to another district, so if certain rules given are found in perfect accord with a mine in which you are interested, you can safely conclude these same principles control all the deposits in the district having the same origin. It must not be assumed however that because one mine on a lode proves rich, all others will be equally valuable, but if a mine in a given district, in the undeveloped stage, shows the same characteristics and is equally rich on the surface as another fully developed mine, it may be reasonably assumed that similar results will follow as in the developed mine.

How Do Faults Affect Ore Bodies?

66. *Faults* in rock masses have previously been explained, and the influence of faults in producing the conditions favorable to the formation of ore bodies has also been considered (See Par. 37), but the forces that produce faults never cease, so that after a perfect ore body has been formed by nature's processes, these are often dislocated by subsequent earth movements, so that what was once a continuous ore body is often divided up into sections more or less widely separated from each other, which makes it also necessary to consider *faulted ore bodies*.

Many a promising prospect or mine has been abandoned because the ore "quit." Afterwards some miner with a little scientific knowledge of faulted ore bodies has taken up the abandoned work and located the lost ore body, perhaps richer than before.

When an ore body splits in its downward course, or thins

out to a point and finally quits, further work is usually fruitless, but where a vein of ore is cut off abruptly, work should not be discontinued, as the ore has simply been dislocated by faulting, and a little practical knowledge will usually enable the miner to find the continuation of the ore body. A fault should never condemn a mine or prospect, as faulted ore bodies frequently occur in the world's greatest mines, in fact a perfectly continuous ore body is rather rare.

A vein may be faulted by another vein, the two continuing as one for a time, and then each may resume its original strike and dip. In such a case, there is no difficulty, as the ore is continuous, and often of increased value as a result of the fault. A vein is often faulted by a dike, and in that case only a section of the ore body, the width of the dike, is dislocated by the intrusion, and the continuation of such a faulted vein or ore body is usually found by driving ahead through the dike, on the same dip as the vein above. On the other hand, veins frequently cut hard dikes, and many miners dwell upon such a fact, when it occurs in their properties, but the fact that a vein cuts a dike only proves continuity of vein, which is important, but veins that cut dikes are *younger* than the dikes, and the lack of age in a vein is a strong indication of imperfect mineralization, so that a vein or ore body that is itself cut or faulted by dikes is much to be preferred.

The term *Fault* is frequently used to denote a fracture or fissure in rock formation, but strictly speaking a Fault in a vein ore body expresses the *amount of the displacement* of the rock strata, and has no reference to the crack or fissure which preceded the fault itself.

67. The Fault Plane is the line of fracture along which the slipping occurs. A fault line or fracture has strike, dip, hanging-wall and foot-wall, like fissure veins, and the defini-

tions given for strike, dip, etc., will apply to fault planes equally well.

With respect to origin, there are several kinds of Faults, but nearly all the faults that occur in metal mining belong to the class known as *Slipped Faults*. With respect to the direction of wall movements along a fault plane, faults are classed as:

- (1) *Normal Faults*, and
- (2) *Reversed Faults*.

68. A *Normal Fault* is the effect of slipping of the hanging wall downward, or a movement of the foot-wall upward, or both these movements combined. Nine out of ten faults are Normal. A *Reversed Fault* is formed by a movement in a reverse direction from a Normal Fault; that is, an upward movement of the hanging wall or slipping down of the foot-wall.

Fig. 70 illustrates a Normal Fault. The diagonal line *A-D* is the Fault Plane. The strata at the right and above the strike plane, forming the hanging wall, has either slipped downward or the foot-wall has been pushed upward. The fault or amount of displacement is represented by the line *B-C*. The horizontal displacement represented by *G-C* is called the *Heave*, and the vertical dislocation, *B-G*, is called the *Throw*.

Suppose an incline shaft at *F* continued along the dip of the vein to point *C*, where it was found to stop abruptly. The presence of "stria" (marks) of slickensides on the walls of the fault plane would confirm the supposition of a faulted vein and ore body. The question then to determine is, whether it is a Normal or Reversed Fault. Inasmuch as Normal Faults are common and Reversed Faults unusual, the presumption would be strong that the hanging wall, or the

portion above the fault plane *A-B*, has slipped down towards the point *D*. The wall markings will often indicate the direction taken by the faulted ore body, or a small seam of ore, sheared off, will often be found on the side of the lost ore body. If these physical evidences are not decisive, a simple rule that can be easily applied is as follows:

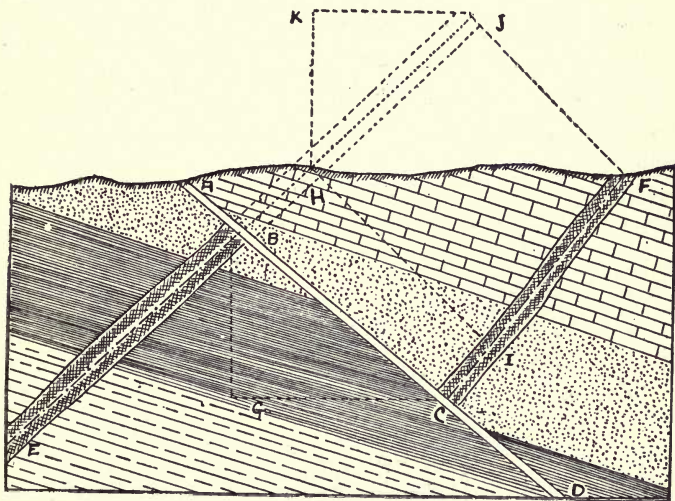


Fig. 70. Ideal Section Illustrating Faulted Ore Bodies.

FAULT RULE.

69. *The continuation of a faulted ore body is always found on the side of the larger angle formed by the intersection of the vein with the fault plane.*

A measurement of the angles may be made by any miner, with an ordinary carpenter's square, which forms a perfect right angle, and the direction of the displaced ore body easily determined.

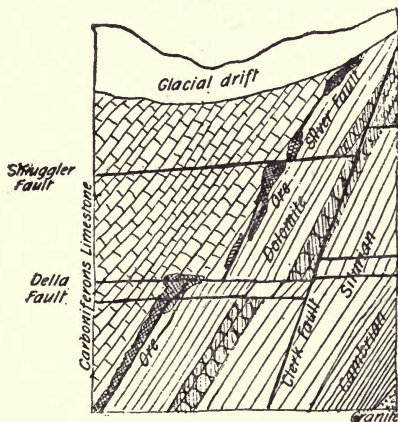
In Fig. 70 the angle formed at *C* by the intersection of the hanging wall of the vein *F* with the hanging wall of the fault plane *A-B* will be *greater* than a right angle, and the lower angle at *C*, formed by the junction of the foot-wall of vein with the fault plane, is plainly *less* than a right angle, which establishes the fact that the displaced ore body is above, the faulted vein appearing at *B-E*. The proper method is to drive upward along the fault plane to reach the point *B*. If on the other hand the larger angle occurs on the opposite side, it would prove a *reversed fault*, and the missing ore body would be found by driving along the fault plane towards *D*. By following this simple rule the *direction only* will be indicated, and the question of the amount of displacement in feet is still left for determination. There are rules for computing the distance between the two sections of a displaced ore body, but they are outside the scope of this book, however, it is often possible to measure a fault on the surface. A fault crossing a mountain will often show by a depression or "saddle." Sometimes the line of a fault can be traced on the surface by the outcropping of rock, whose strike and dip are different from the surrounding strata. The slip or fault may sometimes be actually measured on the side of a cliff or canyon by taking well defined strata above and below and measuring the distance between them, which distance will be approximately the amount of displacement of the ore body within the mine.

These simple methods are practical when the displacement is no more than a few hundred feet, but when a fault runs into the thousands of feet only an accurate knowledge of the geological features of the entire district will be of any value. However, such surface examination will often reveal a fault of such extent that would make it impractical to drive

along the fault plane the required distance to reach the faulted ore body.

Fig. No. 71 shows a series of faults in a Colorado mine. Note the shaded section showing the ore body faulted in its downward course in two places. The "Smuggler" fault is only a slight displacement, but the "Della" fault is greater.

Fig. 71.



VEINS AND FAULTS AT ASPEN.

The greater angles are readily distinguished with the eye, situated to the left, in the direction of the displaced ore. These faults are horizontal and nearly parallel with the surface, and are sometimes called "*Shoved Faults*"; one section of the vein being torn off and shoved away by lateral pressure.

By referring to Fig. 64, illustrating Contact Veins, it will be seen that Vein *E* is faulted normally by contact fissure vein *D*; the "younger strata" representing the hanging wall of vein *D* has slipped downward as indicated by the arrow at

A. The "Blind Fissure," *G*, is a *reversed fault*. The hanging wall of vein *C*, which is also the hanging wall of fault plane *G-C*, has either moved upward or the slate foot-wall has slipped downward.

Note that the larger angle is at the lower side at *G*, showing the direction of the faulted vein, indicated by the arrow and seen in the slate below.

Concluding Observations

The problem of faulted ore body often results in abandonment of a mine or prospect by those unfamiliar with the subject, or the matter is submitted to a Mining Engineer for solution, inasmuch as it involves a knowledge of Geology and higher mathematics, but if the principles named above are thoroughly mastered, the solution of the simple faulting problems that arise in the development of a prospect or mine will be rendered comparatively easy to any one with common school education and good judgment.

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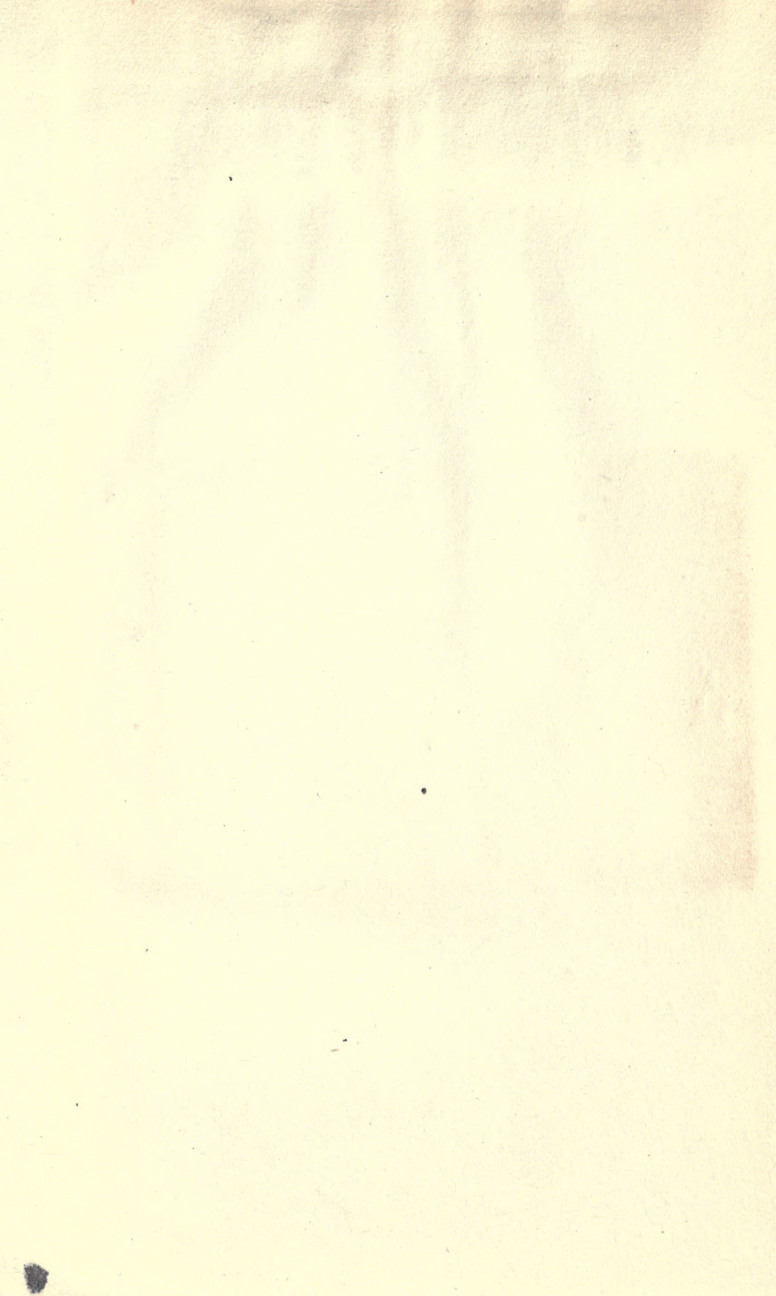
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